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A Study of the Feasibility of Utilizing Solid Wastes for Building Materials Phase III and IV Summary Reports

Material Systems Corp, Escondido, Calif

Prepared for

Municipal Environmental Research Lab, Cincinnati, Ohio Solid and Hazardous Waste Research Div

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A Study of the Feasibility of Utilizing Solid Wastes for Building Materials

Phase III and IV Summary Reports

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16. ABSTRACT

This report summarizes work to develop building materials containing inorganic and organic wastes and wastes-derived products. Attempts were made to produce full-scale products and qualify them for structural applications. Particle board panels were made of peanut hulls and wood waste on production-type equipment. Particle boards of peanut hulls have mechanical properties that are slightly less desirable than those of commercially available boards, and the economics are marginal. However, particle board panels of wood waste can be competitive with commercial products. Two hour, fire-rated structural walls made from inorganic rice hull foam could also be viable, as could floors, roofs, ceilings, and the 90-minute, fire-rated door with a rice-hull foam core and a wood-waste frame. Data were developed for submittal to the International Conference of Building Officials and the U.S. Department of Housing for certification. Structural tests were performed on wall panels fabricated from rice hulls and an inorganic binder. These tests completed generation of the data required for building code approval. Wall panels made of rice hull composite were found to satisfy all structural requirements necessary for use in one- and two-story residential construction, except that resistance to transverse loading (bending) was insufficient.

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A STUDY OF THE FEASIBILITY OF UTILIZING SOLID WASTES FOR BUILDING MATERIALS

Phase III and IV Summary Reports

by

Material Systems Corporation
Escondido, California 92025

Contract No. 68-03-2056

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for preventing, treating, and managing wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for preserving and treating public drinking water supplies, and for minimizing the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research, a most vital communications link between the researcher and the user community.

This project has resulted in savings for the environment and man. Environmental stresses are reduced when waste streams can be productively substituted for natural resources. These building products can benefit man in the areas of both safety and economy. Unique solutions such as these are to be encouraged.

Francis T. Mayo
Director
Municipal Environmental
Research Laboratory

ABSTRACT

This report summarizes work conducted during Phases III and IV of a study by Material Systems Corporation to develop building materials containing organic and inorganic wastes and waste-derived products.

The first phase, April 1974 to July 1974, included an extensive literature search to identify, review, and evaluate wastes with potential as matrices, reinforcements, or fillers in building composites. Following limited laboratory studies, two matrices were selected--an organic resin and an inorganic matrix developed by Material Systems Corporation. Seven reinforcement candidates and five fillers were chosen for detailed evaluation.

The second phase, July 1974 to September 1975, was an evaluation of the structural and aesthetic properties of the various waste composites. Satisfactory products were made using both inorganic and organic systems; structural and fire-resistant properties of several formulations were found to be superior to those of existing commercial products. Economic analyses were performed on the structurally promising products, and several appear to be commercially viable.

In Phase III, September 1975 to November 1976, attempts were made to produce full-scale products and qualifty them for structural applications. Particle board panels, 4 by 4 feet, were made of peanut hulls and wood waste on production-type equipment. Particle boards of peanut hulls have mechanical properties that are slightly less desirable than those of commercially available boards, and the economics are marginal. However, particle board panels of wood waste can be competitive with commercial products. Two-hour, fire-rated structural walls made from inorganic rice hull foam could also be viable, as could floors, roofs, ceilings, and the 90-minute, fire-rated door with a rice-hull foam core and a wood-waste frame. Data were developed for submittal to the International Conference of Building Officials and the U. S. Department of Housing for certification.

The components were incorporated into an 8- by 12-foot demonstration modular unit and erected at the research center in Cincinnati, Ohio.

In Phase IV of the study, structural tests were performed on wall panels fabricated from rice hulls and an inorganic binder. These tests completed generation of the data required for building code approval.

Wall panels made of rice hull composite were found to satisfy all structural requirements necessary for use in one-and two-story residential construction, except that resistance to transverse loading (bending) was insufficient.

Long-term weathering exposure tests of the rice hull composite indicated high sensitivity to moisture degradation. The development of protective coating materials that would prevent moisture penetration and increase the bending resistance of the wall panels is recommended for future work.

Rice hull wall was demonstrated to withstand long fire exposure without structural failure. A wall panel assembly was fully qualified for 1-hour structural fire rating.

The most successful accomplishment of this study was the development of new core and framing materials for fire doors. In an exemplary effort of cooperation between a research organization and a manufacturer of commercial products, new materials were developed for specific application. They were qualified in full-scale tests to meet building code standards and were adapted for economical production. As a result, the manufacturer is planning to introduce into his product line a high-performance, 90-minute fire rated door using materials based on waste products and developed during this study.

This report was submitted in fulfillment of Contract No. 68-03-2056 by Material Systems Corporation under the sponsorship of the U. S. Environmental Protection Agency. This report covers the period December 1976 to February 1977, and work was completed as of February 1977.

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METRIC CONVERSION FACTORS

All measurements in EPA documents are to be expressed in metric units. In this report, however, this practice adversely affects clarity. Conversion factors are therefore given below

METRIC CONVERSION TABLE

English system	Metric system
Inch	2.54 cm
Foot	30.48 cm
Yard	0.914 m
Square inch	6.452 cm^2
Square foot	0.092 m^2
Square yard	0.836 m^2
Cubic inch	16.387 cm^3
Cubic foot (1,728 in^3)	0.028 m^3
Cubic yard (27 ft^3)	0.7646 m^3
°F	-17°C
Pound	
avdp. (16 dr)	453.592 g
troy (12 oz)	373.24 g
Ton	
long (2,240 lb)	1.016 t
short (2,000 lb)	0.907 t

PHASE III SUMMARY REPORT

SECTION 1

INTRODUCTION

Material Systems Corporation and the Solid and Hazardous Waste Research Division of the Municipal Environmental Research Laboratory at Cincinnati, Ohio have initiated a joint effort development study for the application of waste materials for residential and commercial construction. This is a summary report of the Phase III activity. Phase I activity was reported in MSC Technical Report 74-12. This report presented a comprehensive literature search.

The data were reviewed and evaluated for potential matrix, reinforcement, and filler candidates. The more promising candidates were evaluated with limited laboratory studies. From these studies, two types of matrices, furfural derivatives and inorganic, were selected for further study. Seven reinforcement candidated and five fillers were selected for evaluation with the two matrices.

The Phase II activity demonstrated the potential technical and economic feasibility of utilizing waste materials for building construction. As the Phase II study progressed, it became apparent that there existed a multiplicity of product possibilities from waste materials. Therefore, it was jointly decided to concentrate Phase II activity on the development of the product and postpone specific qualifications until Phase III. The development included testing and evaluation to sufficient level to assure probable qualification for specific products. The products selected for qualification studies in Phase III were in two main categories: those materials from organic matrices and those from inorganic matrices.

The Phase III study selected wood waste and peanut shells for possible qualification as organic particle board. Panels as large as four feet by four feet were fabricated and tested. However, not all the processing problems were resolved which would require further studies. The wood waste particle board has some economic advantage over commercial particle boards. The economic advantage of the peanut shell board is marginal. With the resolution of some of the processing problems, the boards could be qualifiable. They do have one limitation and that is density. Boards from this process are limited to a minimum weight of 55 pounds per cubic foot. The details of this study are presented in the section "Waste Products Using an Organic Matrix."

The Phase III study also selected a rice hull foam from an inorganic matrix for the qualification of walls, floors, roof-ceiling, and floor-ceiling systems. A satisfactory load carrying two hour fire-rated wall was developed. An acceptable floor, floor-ceiling, and roof-ceiling system was also developed. All systems have an economic advantage over conventional structures and lend themselves to mass production techniques. Further studies are recommended on the problem of long term loading.

The rice hull foam above was modified to be used as a core for fire doors. A screwable framing material from wood waste-reinforced inorganic matrix was also developed. The resulting core and framing materials both have economic advantages and offer a more reliable 90 minute fire door than do those commercially available.

Details of the organic studies are presented in the section "Waste Products Using an Inorganic Matrix."

The final activity of this study was the construction of an 8-ft. wide, 12-ft. long demonstration unit that incorporates all of the above products. Details are presented in the section "Demonstration Unit Constructed From Waste Products."

SECTION 2

WASTE PRODUCTS USING AN ORGANIC MATRIX

The Phase II study developed a two-step process of "in-situ" formulation of furfural from wastes such as wood, peanut hulls, rice hulls, and cotton stock. It was discovered that materials containing cellulose and pentosans when treated by acid, yield a binder during the process of molding. The acid treatment is very simple. A 3% to 7% solution of hydrochloric, phosphoric, or p-toluene sulfonic acid is used depending on the waste involved. The first step if to soak the material in the acid solution for 30 minutes and then dry it in an oven at 50-60°C. The second step is to transfer the material to a cold mold and cure it under pressure for 2 to 10 minutes. This concept appeared to be a feasible application to the production of particle board. The results of work with 4 inch by 6 inch specimens supported this. However, when a limited quantity of 30 inch by 30 inch panels were made, scale-up problems became apparent but were considered solvable.

The activity of Phase III was then directed to the development of processing conditions which would permit the fabrication of 48 inch by 48 inch panels that could be qualified as exterior structural particle board. The basic conditions to be resolved were as follows:

1) Type and percent of acid absorbed by material
2) Moisture content
3) Time under pressure
4) Press temperature
5) Pressure technique
6) Post cure
7) Pre-heat
8) Particle size

These are discussed in the following text. Prior to initiating the study the candidate waste materials were limited to peanut hulls and wood waste as they provide the most resinous binder by in situ formation.

TYPE AND PERCENT OF ACID ABSORBED BY THE MATERIAL

Peanut Hull Waste--Two acids were considered for use with peanut hull waste--p-toluene sulfonic acid and phosphoric acid. There are no appreciable differences in properties and tests indicate that a 4 to 6% acid absorption by the hulls is the minimum acceptable for either with peanut hulls. The cost of phosphoric acid is $0.18 per pound and the cost of p-toluene sulfonic is $0.25 per pound. Therefore phosphoric acid was used in all peanut hull waste scale-up studies.

To acid soak large quantities of peanut hulls, it was necessary to abandon laboratory methods which soaked the hulls in a 3% solution of 75% acid in water for 15 minutes followed by draining. Later, a washing machine and clothes dryer were effectively used. Bags were sewn with fine polyester mesh fabric and hulls put into these for soaking and centrifuging. Without these bags, the vents in the dryer were rapidly plugged, drying efficiency drastically reduced, and there was also a considerable loss of material. It was obvious that the centrifugation of the soaked peanut hulls would remove much more of the phosphoric acid solution used to treat the hulls, thus leaving behind less acid in the hulls. The properties of the product were greatly affected by the amount of phosphoric acid in the hulls. It was necessary to determine the amount of acid in the hulls when drained by gravity in the lab method on small quantities vs that of the centrifuged material. This was determined by soaking hulls in acid using both methods. The results of this test are presented in Table 1-1. It can be seen from these data that the ratio of hulls to absorbed acid is much greater with the spin process than with the laboratory soak process, therefore a higher acid concentration in the solution was required to achieve equivalent acid absorption. The moisture content was lowered by centrifugation and this was advantageous because of more rapid drying with lower energy consumption.

Another aspect examined for scale-up was the re-use of drained acid solution with added fresh acid solution. By this procedure a considerable cost savings resulted compared to the labscale method where the drained acid was discarded. Titration results are presented in Table 1-2.

After using three times, the acid soaking solution was made strongly alkaline with sodium hydroxide solution and this produced an amine-like order which caused indicator paper to show a pH of 9 for the vapors above the solution. Therefore it appears that peanut hulls contain a basic material which removes hydrogen ion by neutralization but permits reuse up to three times.

The lab method soaking time was reduced from 15 minutes or longer to 5 minutes. This was determined by soaking peanut hulls in 3% acid solution for 5 minutes and 800 minutes (16 hours). The initial ratio of H_1^+/H_2^+ was 0.98. After 5 minutes the ratio was 0.785 and after 800 minutes it was 0.79, indicating no further change after 5 minutes.

After establishing the method of acid absorption, two large-scale mixes were made to produce material for use in full scale process studies at Washington State University. The solution used was 8 gallons of a 7% solution of 75% phosphoric acid in water for 8.82 pounds of hulls. The acid utilizationis presented in Table 1-3. These samples were further dried at Washington State University removing more of the acid and solution. Table 1-4A shows the results with varying acid content on 4 inch by 6 inch panels and 1-4B on 12 inch by 15 inch panels. It would

TABLE 1-1 COMPOSITION BY % WEIGHT OF PEANUT HULLS - PHOSPHORIC ACID MIXTURE

Method	% Hulls	% Acid (100% Concentrate	% Water	Hulls/Acid
Lab Process Test #1	20.7	2.3	77.0	9.0
Test #2	23.1	2.2	74.7	10.5
Test #3	24.9	2.2	72.9	11.3
Spin and Dry after 3% Sol of 75% Acid in water	43.1	1.66	55.2	26.0
Spin and Dry after 7% sol of 75% Acid in water	44.4	3.64	52.0	12.2

TABLE 1-2 TITRATION STUDIES OF PHOSPHORIC ACID SOAK SOLUTIONS WITH REUSE

Theoretical Molarity = 0.224

Item	0-Use	1-Use	2-Use	3-Uses
H_1^+ (pH 5.75)	0.215 Molar	0.161	0.115	0.062
H_1^+ (pH 8.6)	0.213 Molar	0.218	0.220	0.194
Am't of 1st Hydrogen Used	0	25%	47%	71%
Am't of 2nd Hydrogen Used	0	0	0	0

TABLE 1-3 ACID USED IN LARGE-SCALE MIXER

Wt of Peanut Hulls	Wt. of 75% Phosphoric Acid	% of 100% Acid to Hulls
1000	73.51	5.5%
1300	117.62	6.8%

TABLE 1-4A SMALL PEANUT HULL PANELS MADE WITH PHOSPHORIC ACID

4 x 6 in. Panels

	MATERIAL			MOLDING CONDITIONS		
Reference Book No. 69	Acid (g/100g of chips)	%Moist Content *	Mold Temp (^{O}F)	Pressure (psi)	Pressure Relief Cycle (min)	Time Under Pressure (min)
30-14	4.96	9.0	377	750	None	10
30-15	4.96	9.0	385	750	None	10
30-16	4.96	9.0	418	750	3,5,7,9	10
30-17	2.53	6.6	418	750	3,5,7,9	10
30-18	0.885	8.6	415	1000	None	10
38-1	4.96	9.0	437	1000	1,3,5,7 9,11,13	15
38-2	4.96	9.0	445	1000	2,4	15
38-3	4.96	5.5	430	1000	6,8,10, 12,14	15
38-4	4.96	9.0	350	500	None	26
38-5	4.96	1.3	349	500	None	25
38-6	4.96	9.0	377	750	None	25
38-7	4.96	9.0	405	750	2,8	20
38-10	4.96	2.8	432	1000	4,10	10
38-11	4.96	2.8	432	1000	5	15
42-21	4.19	7.1	350	750	None	10
42-22	6.28	6.1	345	750	None	10
42-23	6.28	6.1	370	750	None	10
30-12	4.15	11.3	427	750	None	4
30-13	2.02	8.9	432	1000	None	10
38-8	1.044	6.9	416	1000	None	20
38-9	1.044	6.9	435	1000	14	20
42-19	1.62	11.1	395	1000	None	10
42-20	3.45	11.8	379	1000	6,8	10

*10 grams, 1 hour @ 300^{O}F in forced-air oven.

(continued)

TABLE 1-4A (Continued) SMALL PEANUT HULL PANELS MADE WITH PHOSPHORIC ACID

		PROPERTIES OF MOLDED PANEL				
					Flex-Mor (psi)	
Reference Book	Blown Area	Relative Shrinkage	Density (lbs/ft^3)	Hardness Shore D	Initial (avg. of 3)	24-hr water soak (avg of 2)
30-14	0	High	60	67	971	239
30-15	0	V. High	63	73	1002	397
30-16	0	V. High	70	79	1934	1445
30-17	0	V. High	66	74	1810	1280
30-18	0	Medium	57	66	857	53
38-1	0	V. High	74	77	1846	895
38-2	80	V. High	77	83	2677	688
38-3	40	V. High	73	78	2469	636
38-4	0	High	59	72	1079	177
38-5	0	High	55	45	664	51
38-6	0	High	65	70	2082	974
38-7	100	V. High	70	82	2358	1555
38-10	Expl.	-	71	-	-	-
38-11	Expl.	-	-	-	-	-
42-21	0	High	61	69	1422	699
42-22	0	High	51	58	460	22
42-23	0	High	55	61	472	88
30-12	Expl.	V. High	57	61	-	-
30-13	0	V. High	68	70	1728	412
38-8	0	High	60	68	1135	88
38-9	0	V. High	65	76	1170	551
42-19	0	V. High	58	72	962	211
42-20	100	V. High	72	80	1749	1096

TABLE 1-4B MEDIUM-SIZED PEANUT HULL PANELS MADE WITH PHOSPHORIC ACID (12" x 15")

MATERIAL				MOLDING CONDITIONS		
Reference Notebook #69	Acid (g/100g) of chips	Moisture WSU Method %	Platten Temp (°F)	Pressure psi	Pressure Relief Cycle (min)	Time Under Pressure (min)
46-1	3.98	5.5	375	1000	None	7
46-2	3.98	5.5	375	1000	5	10
46-3	3.98	5.5	375	1000	5,10 Blew	15
46-4	3.98	5.5	340	1000	5	10
46-5	3.98	5.5	390	1000	5	10
46-6	3.98	5.5	390	1000	5,10	15

PROPERTIES OF PANEL

Reference Notebook #69	Charge Size grams	Thickness	Density lb/ft^3	Internal BOND IB psi	Flexure MOR psi	Flexure MOE x10^6 psi	Notes
46-1	1900	-					Blown
46-2	1900	0.542	65	164	2087	0.470	OK
46-3	1900	-					Blown
46-4	1900	0.525	65	195	2150	0.487	OK
46-5	1800	0.525	64	147	2112	0.466	OK
46-6	1800	0.545	64	183	2132	0.492	Blown

appear that acceptable panels can be made with a 4% acid content. For further discussion see the section on Full Scale Production Studies.

Wood Waste--There were three types of wood waste evaluated. The waste from Ponderosa Pine, Southern Hard Pine, and Douglas Fir. These wood wastes were evaluated with different percentages of acid absorption and with both phosphoric acid and p-toluene sulfonic acid. The results are presented in Tables 1-5 through 1-10. As Tables 1-5 and 1-6 show, Ponderosa Pine does not provide an acceptable product with this system. Hard Pine, as shown in Table 1-7, provided better results. However, the best results were obtained with Douglas Fir (see Tables 1-8 through 1-10). It appears that the best results were achieved consistently with p-toluene sulfonic acid. The effect of acid absorption from 0.35% to 4.22% did not appear to make much difference. Therefore, it was decided to try the full range of acid absorption. The phosphoric acid required 4.5% to 6.5% absorption. This percentage with wood waste made the product economically undesireable. It was hoped that a small wood waste at Washington State University to save the shipping cost. When work was started at Washington State University, it was found that the commercially available Douglas Fir waste had a different geometry than that supplied Material Systems Corporation by Washington State University in the previous work.

The previous work on 4 inch by 6 inch panels was repeated for the range of acid absorption. The results are shown in Tables 1-11 and 1-12. Acid absorption of 0.38% appears to provide properties generally equivalent to that of 4%. Tables 1-11 and 1-12 used a technical grade of p-toluene sulfonic acid and Table 1-13 examined a less expensive commercial grade which resulted in lower properties.

A series of larger panels, 12 x 15 inches, were then made to more closely approximate full scale production problems with 0.35% acid absorption and 1.78% acid absorption being used. The 0.35% yielded too little resinous binder and the 1.78% generated too much. Combining the two materials in quantities of 60% - 67% of 1.78% absorption and 33% - 40% of 0.35% absorption, yielded potentially acceptable results. These data are shown in Table 1-14.

Because of the relatively long time required to produce acid treated particles with the soak-dry method, and the limited time available on the Washington State University presses, it was decided to use the Washington State University spray equipment to make acid treated particles.

The acid was sprayed onto the wood chips using 20 grams of 25% p-toluene sulfonic acid in water, per pound of wood. A small amount of insoluble impurity (presumably sulfone) had to be filtered out of the solution to protect the spray nozzles against stoppage. This resulted in a material with an acid absorption content of 1.05%. The results are shown in Table 1-15.

MOISTURE CONTENT

Peanut Hull Waste--Only limited variation on the effect of moisture

TABLE 1-5 PROCESSING STUDIES ON PONDEROSA PINE
500 psi Pressure

Acid Solution Concentration	Process Conditions	Moisture Content	Shore"D" Hardness		Density	Modulus of Rupture H_2O Soak
			Top	Bottom		
H_3PO_4 7%	5 min 300°F	10%	61	63	1.00	699
H_3PO_4 7%	5 min 300°F	10%	34	37	1.00	-
H_3PO_4 7%	3 min 325°F	10%	58	59	0.95	661
H_3PO_4 7%	3 min 325°F	10%	32	33	0.95	-
H_3PO_4 7%	5 min 325°F	10%	63	68	1.05	1103
H_3PO_4 7%	5 min 325°F	10%	36	41	1.05	-
H_3PO_4 7%	10 min 325°F	10%	65	72	1.10	1333
H_3PO_4 7%	10 min 325°F	10%	45	51	1.07	-
H_3PO_4 7%	5 min 350°F	10%	73	77	1.03	1035
H_3PO_4 7%	5 min 350°F	10%	47	54	1.03	-
H_3PO_4 7%	3 min 350°F	10%	60	76	1.07	1242
H_3PO_4 7%	3 min 350°F	10%	41	44	1.03	-
H_3PO_4 7%	5 min 300°F	6%	48	52	0.79	373
H_3PO_4 7%	5 min 300°F	6%	13	17	0.83	-
H_3PO_4 7%	3 min 325°F	6%	57	56	0.83	462
H_3PO_4 7%	3 min 325°F	6%	9	13	0.83	-
H_3PO_4 7%	5 min 325°F	6%	57	62	0.83	776
H_3PO_4 7%	5 min 325°F	6%	18	26	0.88	-
H_3PO_4 7%	10 min 325°F	6%	75	79	1.09	1729
H_3PO_4 7%	10 min 325°F	6%	57	59	1.09	-
H_3PO_4 7%	3 min 350°F	6%	62	61	0.95	1358
H_3PO_4 7%	3 min 350°F	6%	35	40	0.93	-
H_3PO_4 7%	5 min 350°F	6%	68	71	1.06	1758
H_3PO_4 7%	5 min 350°F	6%	58	56	1.08	-
tosic 3% *	5 min 250°F +	7%	55	63	0.90	970
tosic 3%	5 min 250°F	7%	63	66	0.90	-
tosic 3%	2 min 295°F ‡	7%	62	61	1.23	1726
tosic 3%	2 min 295°F	7%	57	55	0.98	-

* *p*-toluene sulfonic acid.
+ Postcured 1hr/275°F.
‡ Postcured 1hr/300°F.

TABLE 1-6 PROCESSING STUDIES ON PONDEROSA PINE USING MIXED ACID

4% H_3PO_4 + 0.7% P-Toluene Sulfonic Acid

500 psi Pressure

Process Conditions	Moisture Content	Shore "D" Hardness		Density	Modulus of Rupture
		Top	Bottom		
5 min 275°F	2% *	63	65	1.01	1134
5 min 275°F	2%	49	51	1.13	-
3 min 292°F	2%	57	59	0.99	1335
3 min 292°F	2%	44	46	1.13	-
5 min 300°F +	7%	70	71	1.20	1764
5 min 300°F	7%	59	62	1.27	-
5 min 310°F	2%	68	62	1.10	1396
5 min 310°F	2%	65	67	1.21	-

* With 7% water content, panel exploded on pressure release.

+ Panel Blown. Remolded 10 min/50 psi + 10 min/500 psi.

TABLE 1-7 PROCESSING VARIABLES, TREATMENT OF HARD PINE WOOD USING PHOSPHORIC ACID

Moisture Content = 9.9%

	MATERIAL				MOLDING CONDITIONS	
Reference Book No. 69	Acid * (g/100g of chips)	Moisture (%) +	Mold Temp (°F)	Pressure psi	Total Time Under Pressure (min)	Blown Area (5)
20-3	9.42	7.0	375	500	3.5	100
20-10	9.42	7.0	320	500	7.0	60
20-2	6.42	7.0	380	500	7.0	100
20-11	6.42	7.0	327	500	5.0	0
20-13	6.42	7.0	337	500-400	10.0	80
20-1	3.26	7.0	385	500	10.0	20
20-12	3.26	7.0	340	500-750	10.0	0
20-14	(50%-9.42) (50%-3.26)	7.0	333	500	7.0	0

		PROPERTIES OF MOLDED PANEL		FLEX-MOR (psi)	
Reference Book No. 69	Relative Shrinkage	Density lbs/ft^3	Hardness Shore D	Initial (Avg of 3)	24-hr water soak (Avg of 2)
20-3	V. High	65	58	1480	605
20-10	Medium	74	63	1530	585
20-2	V. High	62	69	1170	573
20-11	Medium	61	57	1195	89
20-13	Medium	63	66	1130	694
20-1	High	66	71	2055	698
20-12	Low	57	69	840	18
20-14	Low	69	77	1800	362

* Given as 100% acid, although 75% acid was used and based on dry wood chips.

+ 10 grams, 1 hour @ 300°F in forced-air oven.

TABLE 1-8 PROCESSING VARIABLES, TREATMENT OF DOUGLAS FIR

Hammermilled to -6+14 mesh; Moisture Content=7.5%
Phosphoric Acid Treatment

MATERIAL			MOLDING CONDITIONS					PROPERTIES OF MOLDED PANEL			
Reference Book No. 69	Acid * (g/100g) of chips	Moisture (%) +	Mold Temp (°F)	Pressure psi	Pressure Relief Cycle (min)	Time Under Pressure (min)	Blown Area	Relative Shrinkage	Density lbs/ft^3	Hardness Shore D	Flex-Mor (psi) Initial (avg of 3)
20-5	6.45	7.0	372	500	None	10.0	100	High	68	77	1545
20-7	6.45	7.0	370	500	None	5.0	0	Med	67	75	1780
20-16	6.45	7.0	358	500-750	None	10.0	100	Med	71	80	1565
20-17	6.45	7.0	355	875	None	2.5	100	Low	67	72	1420
20-18	6.45	7.0	400	250	None	4.5	0	Low	-	56	1400
20-6	4.58	7.0	372	500	None	10.0	20	Med	71	82	2345
20-8	4.58	7.0	362	500	None	5.0	0	Low	55	59	545
20-15	4.58	7.0	362	625	None	9.5	0	High	68	55	1925
22-23	4.58	7.0	372	750	2,3,4	4.5	40	-	72	80	2349
22-25	4.58	7.0	370	500	7	10.0	60	-	71	65	2189
22-26	4.58	7.0	325	625	None	15.0	40	-	58	59	1178
20-4	2.33	7.0	378	500	None	10.0	0	Low	54	49	750
20-9	2.33	7.0	403	500	None	10.0	20	Med	70	74	2025
20-19	2.33	7.0	397	500	None	4.0	0	Low	54	70	703
20-20	2.33	7.0	358	875	None	10.0	0	-	60	59	1007
20-21	2.33	7.0	382	875	None	8.0	60	-	71	74	2020
20-22	2.33	7.0	380	875	3,6	8.0	0	-	69	72	2018

* Given as 100% acid, although 75% acid used and based on dry wood chips.
+ 10 grams, 1 hour @ 300°F in forced-air oven.

TABLE 1-9 PROCESSING VARIABLES, TREATMENT OF DOUGLAS FIR

Hammermilled to -6+14 mesh; Moisture Content = 8.5%
Treated with p-Toluene Sulfonic Acid

MATERIAL				MOLDING CONDITIONS		
Reference Book No. 69	Acid * (g/100g of chips)	Moisture (%) +	Mold Temp (°F)	Pressure psi	Pressure Relief Cycle	Total Time Under Pressure
26-3	5.49	13.1	300	500	None	5.0
26-10	5.49	13.1	280	500	None	5.0
26-1	2.21	14.3	340	500	None	5.0
26-11	2.21	14.3	260	500	None	5.0
26-16	0.46	4.1	307	750	None	15.0
26-19	0.46	4.1	392	750	3	7.0

		PROPERTIES OF MOLDED PANEL			
Reference Book No. 69	Blown Area (%)	Relative Shrinkage	Density lbs/ft^3	Hardness Shore D	Flex-Mor psi Average of 3
26-3	100	V. High	70	50	1810
26-10	80	High	77	74	2455
26-1	100	V. High	67	64	1185
26-11	0	High	63	72	1025
26-16	0	-	52	60	V. Weak
26-19	100	Medium	73	67	2057

* Given as 100% acid, although 75% acid was used and based on dry wood chips.

+ 10 grams, 1 hour @ 300°F in forced-air oven.

Note: Pine wood shavings from MSC planer (8.5% moisture)
p-Toluene Sulfonic Acid (100%)

TABLE 1-10 PROCESSING VARIABLES, TREATMENT OF DOUGLAS FIR
Hammermilled to -6+14 mesh; Moisture Content = 6.6%
Treated with p-Toluene Sulfonic Acid

MATERIAL		MOLDING CONDITIONS					PROPERTIES OF MOLDED PANEL				
Reference Book No. 69	Acid * g/100g of chips	Moisture (%) +	Mold Temp (°F	Pressure (psi)	Pressure Relief Cycle (min)	Time Under Pressure (min)	Blown Area (%)	Relative Shrinkage	Density (lbs/ft 3)	Hardness Shore D	Flexure MOR (psi) (avg of 3)
26-4	4.22	9.5	275	500	None	5	0	Medium	74	77	2955
26-8	4.22	9.5	262	500	None	8	0	Medium	69	69	1845
26-9	4.22	9.5	275	1000-	None	5	0	Medium	67	66	1960
26-12	4.22	9.5	272	500	None	10	0	Medium	75	79	3414
26-13	4.22	9.5	277	500	None	5.5	0	Medium	74	81	3058
26-14	4.22	9.5	273	500	None	5	0	Medium	75	84	2887
30-3	3.99	7.9	345	500- 45	None	8	0	Medium	57	68	1276
30-4	3.99	7.9	350	500- 0	None	6	0	Medium	52	64	862
26-2	1.72	11.4	350	500	None	5	100	V. High	54	44	420
26-5	1.72	11.4	307	1000- 500	1	5	100	High	76	76	2010
26-6	1.72	11.4	308	1000- 2000	1,3	10	60	Medium	74	64	2055
26-7	1.72	11.4	288	1000- 1000	1	5	0	Medium	65	45	815
30-1	1.72	11.4	353	750	1,2,3, 4,5,6, 7,8,9	10	100	V. High	73	76	744
30-2	1.72	11.4	265	500-	None	10	0	Medium	72	80	1351
30-10	1.64	14.1	282	500- 200	None	10	0	Low	56	48	263

(continued)

TABLE 1-10 (Continued) PROCESSING VARIABLES, TREATMENT OF DOUGLAS FIR

MATERIAL		MOLDING CONDITIONS					PROPERTIES OF MOLDED PANEL				
Reference Book No. 69	Acid * g/100g of chips	Moisture + (%)	Mold Temp (^{o}F)	Pressure (psi)	Pressure Relief Cycle (min)	Time Under Pressure (min)	Blown Area (%)	Relative Shrinkage	Density (lbs/ft^3)	Hardness Shore D	Flexure MOR (psi) (avg of 3)
30-11	1.64	14.1	303	500-165	None	15	0	Low	57	56	424
26-15	0.35	13.4	302	750	5,10	15	0	Low	56	55	234
26-17	0.35	13.4	355	750		15	0	Low	62	76	1264
26-20	0.35	13.4	407	750	2,5	7	20	Medium	73	68	2386
26-21	0.35	13.4	415	750	5,10,11	15	60	Medium	71	73	2701
26-18	0.35	13.4	388	750	3	10	0	Medium	73	74	2391

* Given as 100% acid, although 75% acid was used and based on dry wood chips.

+ 10 grams, 1 hour @ 300^{o}F in forced-air oven.

TABLE 1-11 COMMERCIAL DOUGLAS FIR (-17 MESH) WITH P-TOLUENE SULFONIC ACID *

4 x 6 in. Panels

	MATERIAL		MOLDING CONDITIONS				PROPERTIES OF MOLDED PANEL				
Reference Book No. 69	Acid g/100g of chips	Moisture + (%)	Mold Temp (^{o}F)	Pressure (psi)	Pressure Relief Cycle (min)	Time Under Pressure (min)	Blown Area (%)	Relative Shrinkage	Density (lbs/ft^3)	Hardness Shore D	Flex-MOR (psi) (avg of 3)
42-41	4.38	8.2	265	1000	None	5	0	Medium	79	82	3550
42-42	4.38	8.2	297	1000	None	15	0	Low	45	46	274
42-18	4.38	11.4	265	1000	None	5	100	Medium	72	80	1749
38-14	4.38	16.4	292	1000	None	6.5	80	Low	80	77	2210
38-15	4.38	16.4	268	1000	1,2,3, 5,8	5	82	Medium	82	77	2940

* Aldrich Chemical Co. technical grade p-toluene sulfonic acid monohydrate.

+ 10 grams, 1 hour @ 300°F in forced-air oven.

TABLE 1-12 COMMERCIAL DOUGLAS FIR (+17 MESH) WITH P-TOLUENE SULFONIC ACID *

4 x 6 in. Panels

MATERIAL			MOLDING CONDITIONS				PROPERTIES OF MOLDED PANEL				
Reference Book No. 69	Acid g/100g of chips	Moisture + (%)	Mold Temp (%)	Pressure (psi)	Pressure Relief Cycle (min)	Time Under Pressure (min)	Blown Area (%)	Relative Shrinkage	Density (lbs/ft^3)	Hardness Shore D	Flex-MOR (psi) (avg of 3)
38-16	0.380	7.7	398	750	None	10	100	Medium	76	79	2588
38-12	0.380	11.0	395	750	1,2,3, 5,8	10	80	Low	70	76	2290
42-43	4.03	7.3	310	250	None	15	0	Medium	52	70	1104
42-40	4.03	7.3	265	750	None	6	0	Low	77	77	3403
38-17	4.03	10.2	268	750	None	5	0	Medium	78	80	3016
42-25	4.03	10.2	262	750	None	5	0	High	70	80	2414
38-13	4.03	16.0	274	500	None	5	0	Medium	74	67	1450

* Aldrich Chemical Co.. technical grade p-toluene sulfonic acid monohydrate.

+ 10 grams, 1 hour @ 300°F in forced-air oven.

TABLE 1-13 COMMERCIAL DOUGLAS FIR WITH ULTRA TX ACID *

4 x 6 in. Panels

MATERIAL			MOLDING CONDITIONS			
Reference Book No. 69	Acid (g/100g of chips	Moisture + (%)	Mold Temp ($^{\circ}$F)	Pressure (psi)	Pressure Relief Cycle	Total Time Under Pressure (min)
42-32	0.305	10.0	390	750	7	12
42-33	0.305	10.0	370	750	7	12
42-34	0.305	10.0	375	750	7,14	20
42-29	0.305	10.0	265	500	None	5
42-30	2.384	13.3	260	500	None	5
42-31	2.699	13.0	270	500	None	5

PROPERTIES OF MOLDED PANEL

Reference Book No. 69	Blown Area (%)	Relative Shrinkage	Density (lbs/ft^3)	Hardness Shore D	Flex-MOR (psi) (avg. of 3)	Avg. Particle Size
42-32	0	High	70	78	1375	On 17 mesh
42-33	100	High	72	78	1673	On 17 mesh
42-34	100	High	72	73	1813	On 17 mesh
42-29	0	-	48	-	-	-
42-30	0	Medium	62	67	1477	On 17 mesh
42-31	0	Medium	65	77	2094	Thru 17

* Witco Chemical Co. commercial grade *p*-toluene sulfonic acid.

+ 10 grams, 1 hour @ 300°F in forced-air oven.

TABLE 1-14 LONGVIEW DOUGLAS FIR (ON 20 MESH)/P-TOLUENE SULFONIC ACID
12" x 15" x 0.5"

MATERIAL			MOLDING CONDITIONS			
Reference Book No. 69	Acid (g/100g of chips)	Moisture WSU Method %	Platten Temp (°F)	Pressure psi	Pressure Relief Cycle (min)	Time Under Pressure (min)
46-10	0.35	1.5	390	750-1500	7	12
46-11	0.35	1.5	390	1100-1500	7	12
46-12	0.35	1.5	390	1100	7	12
46-13	0.35	5.5	390	1100	7	12
46-14	1.78	3.0	300	1000	None	5
46-20	1.78	3.0	300	1000	None	7
46-22	1.78	3.0	300	1000	None	7
46-15	75%-1.78 25%-0.35	3.6	310	1000	None	6
46-16	75%-1.78 25%-0.35	3.6	310	750	None	8
46-17	67%-1.78 33%-0.35	3.8	300	750	14 blew	15
46-18	67%-1.78 33%-0.35	3.8	300	1000	None	8
46-19	67%-1.78 33%-0.35	3.8	300	1000	None	10
46-21	60%-1.78 40%-0.35	4.0	300	1100	None	7

(continued)

TABLE 1-14 (Continued) LONGVIEW DOUGLAS FIR (ON 20 MESH)/P-TOLUENE SULFONIC ACID

PROPERTIES OF PANEL

Reference Book No. 69	Time to Relieve Pressure (min)	Charge Size (grams)	Thickness	Density lbs/ft^3	Internal Bond IB/psi	Flexure		Notes
						MOR psi	MOE $x10^6$ psi	
46-10	0	1800	(0.5)	-	-	-	-	Blown
46-11	0	1800	-	-	-	-	-	Blown
46-12	0	1600	-	-	-	-	-	Blown
46-13	0	1600	-	61	-	-	-	Crumbly
46-14	0	1700	0.470	70	-	-	-	Blown
46-20	1	1800	-	-	-	-	-	Blown
46-22	0	1800	-	-	-	-	-	Blown
46-15	0	1700	0.505	65	-	-	-	Blown
46-16	1	1700	0.502	64	-	-	-	Blown
46-17	3	1900	-	-	-	-	-	Blown
46-18	2	1800	0.491	70	-	-	-	Blown
46-19	2	1800	0.504	68	22	1516	0.594	OK
46-21	0	1800	0.508	68	14	2096	0.783	Blown

TABLE 1-15 LONGVIEW DOUGLAS FIR (+20 MESH)/P-TOLUENE SULFONIC ACID SPRAY METHOD

12" x 15" x 0.5"

MATERIAL			MOLDING CONDITIONS			
Reference Book No. 61	Acid (g/100g of chips)	Moisture WSU Method %	Platten Temp (°F)	Pressure psi	Pressure Relief Cycle (min)	Time Under Pressure (min)
50-40	1.046	7.8	325	1100	None	8
50-41	1.046	7.8	325	1100	5	10
50-42	1.046	7.8	340	1100	5	10
50-43	1.046	7.8	340	1100	6	10

PROPERTIES OF PANEL

Reference Book No. 69	Time to Relieve Pressure (min)	Charge Size (grams)	Thickness	Density lbs/ft^3	Flexure MOR psi	MOE x10^6 psi	Notes
50-40	0	1800	0.519	68	-	-	Blown
50-41	1	1800	-	-	-	-	OK
50-42	1	1800	0.492	68	2402	0.781	Blown
50-43	1	1800	0.512	65	2144	0.685	Blown

content was evaluated for peanut hull waste. This study is reflected in Table 1-4. No real effect is discernible. For the purpose of the large scale work a moisture content between 5% and 6% was selected. This was similar to that now used in the industry and was considered on the basis of the data from Table 1-4 to be the most reliable.

Wood Waste--The results from limited studies on the effect of moisture on wood waste are presented in Tables 1-11 through 1-13 for 4 inch by 6 inch panels. These results show no real trend. However, when tests were conducted on larger panels (12 inch by 15 inch) it was shown that increasing the water content from 1.5% to 5.5% assisted the processing of 0.35% acid absorbed mixture (see Table 1-14). Further studies showed that a mixture of 0.35% and 1.78% acid absorbed material with 3.8% moisture was better (see Table 1-14). Table 1-15 presents the results of a study on an acid content similar to the mix in Table 1-14 but with a 7.8% moisture content and achieves similar results. This indicates that moisture content has an effect on processing although of less importance than the other parameters.

TIME UNDER PRESSURE

Peanut Hull Waste--Pressure and time are interrelated. The initial studies with time under pressure included the effects of water soak. Table 1-16 presents the effect of molding time on properties for a 375° and a 500 psi cure with a material moisture content of 13%. Table 1-17 presents similar data for a material moisture content of 9%. There is a definite relationship between press cure time and density and a relationship between density and strength retention with water pick up. Longer press cure times can be expected to produce more resin. Increased resin decreases voids which reduces water pick up that effects strength loss. There is a point where further generation of resin becomes self-defeating because the chemical reactions forming the resinous material will eventually lead to excessive shrinkage and eventual cracking of the laminate. From this study, it can be concluded that a minimum of 5 minutes press times is required at a cure temperature of 375°F to generate sufficient resin for satisfactory properties.

If the generation of resin is a function of time and temperature, it can be theorized that shorter times with higher temperatures will produce equal results to longer times and lower temperatures. Temperatures up to 450°F were evaluated with shorter times. The results are presented in Table 1-18. As can be seen, times less than 5 minutes show a marked decrease in initial properties as well as resistance to water.

Wood Waste--The work on peanut hulls was applicable to wood waste. The effects of variations of time under pressure for Ponderosa Pine are presented in Table 1-5, for Hard Pine in Table 1-7, and for Douglas Fir in Tables 1-8 through 1-15. Cure times of 5 minutes appear to be minimum and between 5 and 10 minutes optimum.

TABLE 1-16 EFFECT OF MOLDING TIME ON PROPERTIES
Peanut Hull Composites

Cure Temp - 375°F; Cure Pressure - 500 psi; Moisture Content - 13.0%

Specimen No.	Mold Time (mins)	Weight, grams Hrs, H_2O soaked			Flexural Strength, psi Hrs, H_2O soaked	
		0	2	24	0	24
1-1	15	25.7	-	-	1689	-
1-2	15	28.6	-	-	1642	-
1-3	15	27.7	-	-	1774	-
Average	-	-	-	-	1701	-
6-1	15	26.4	27.7	38.9	-	1268
6-2	15	26.1	27.1	28.7	-	1443
6-3	15	25.0	26.4	28.5	-	1215
Average	-	-	-	-	-	1308
7-1	10	27.7	-	-	1765	-
7-2	10	26.4	-	-	1647	-
7-3	10	27.4	-	-	1561	-
Average	-	-	-	-	1658	-
8-1	10	28.4	30.8	34.3	-	933
8-2	10	26.5	29.6	32.6	-	674
8-3	10	29.4	31.7	36.2	-	576
Average	-	-	-	-	-	728
9-2	5	27.5	-	-	1078	-
9-1	5	29.4	39.9	42.6	-	170
9-3	5	28.5	41.4	43.4	-	100
Average	-	-	-	-	-	135
Whittaker *1	6	62.5	-	-	358	-
2	6	58.9	-	-	333	-
3	6	60.5	-	-	366	-
Average	-	-	-	-	352	-
4	6	60.2	88.1	91.7	-	44
5	6	61.3	87.4	91.7	-	66
6	6	60.9	92.4	96.5	-	29
Average	-	-	-	-	-	46

* Panel made at Whittaker Corp. on 24" x 24" press to 0.5" thickness under Phase II. All other specimens made at MSC to 0.250-0.300" thickness. Moisture content of peanut hulls used to make panel at Whittaker Corp. was 14.0%.

TABLE 1-17 EFFECT OF MOLDING TIME ON PROPERTIES
Peanut Hull Composites

Cure Temp - 375°F; Cure Pressure - 500 psi; Moisture Content - 9.0%

Specimen No.	Mold Time* (mins)	Weight, grams Hrs, Hot Box		Weight, grams Hrs, H_2O Soak		Flexural Strength, psi Hrs Exposure		
		0	24	2	24	0	24HB	24H_2O
2-1	5	-	-	-	-	1164	-	-
2-2	5	-	-	-	-	1112	-	-
2-3	5	-	-	-	-	1220	-	-
Average	-	-	-	-	-	1165	-	-
3-1	5	30.6	34.2	-	-	-	283	-
3-2	5	29.7	33.2	-	-	-	306	-
3-3	5	29.9	33.5	-	-	-	232	-
Average	-	-	-	-	-	-	274	-
1-1	5	-	-	29.6	43.7	-	-	178
1-2	5	-	-	30.0	41.8	-	-	196
1-3	5	-	-	28.9	41.9	-	-	200
Average	-	-	-	-	-	-	-	191
6-1	3	-	-	-	-	1293	-	-
6-2	3	-	-	-	-	1194	-	-
6-3	3	-	-	-	-	1240	-	-
Average	-	-	-	-	-	1242	-	-
5-1	3	30.4	32.9	-	-	-	179	-
5-2	3	31.2	33.4	-	-	-	304	-
5-3	3	30.4	32.1	-	-	-	177	-
Average	-	-	-	-	-	-	220	-
4-1	3	-	-	31.6	55.6	-	-	43
4-2	3	-	-	31.7	50.7	-	-	52
4-3	3	-	-	31.5	52.7	-	-	62
Average	-	-	-	-	-	-	-	52
8-1	2	-	-	-	-	407	-	-
8-2	2	-	-	-	-	342	-	-
8-3	2	-	-	-	-	288	-	-
Average	-	-	-	-	-	346	-	-
	2	-	-	-	-	-	37	-
	2	-	-	-	-	-	64	-
	2	-	-	-	-	-	43	-
Average	-	-	-	-	-	-	48	-
11-1	1	-	-	-	-	284	-	-
11-2	1	-	-	-	-	333	-	-
11-3	1	-	-	-	-	352	-	-
Average	-	-	-	-	-	323	-	-
12-1	1	31.1	34.1	-	-	-	11	-
12-2	1	30.3	32.5	-	-	-	12	-
12-3	1	31.6	33.9	-	-	-	26	-
Average	-	-	-	-	-	-	16	-

* Specimens molded for 1 and 2 minutes were useless after 2-hr. soak.

TABLE 1-18 EFFECT OF HIGH PRESS TEMPERATURES AND SHORTER PRESS TIMES ON PROPERTIES OF PEANUT HULL WASTE PANELS

Pressure - 500 psi   Moisture Content - 3%

Press Temp °F	Press Time (minutes)	% Weight Gain after Water Soak		Flexural Strength, psi after Water Soak		
		2hrs	24hrs	0 hrs	2 hrs	24 hrs
410	5	10	40	1672	1279	191
410	5	11	35	1600	1263	274
410	5	9	18	1502	1100	988
425	5	12	14	1403	1184	1052
425	5	11	20	1764	813	883
425	5	17	44	1330	826	184
450	5	All attempts to make panels resulted in serious blowing.				
410	3	*	*	670	*	*
410	3	*	*	537	*	*
425	3	*	*	937	*	*
425	3	*	*	1303	*	*
410	2	*	*	504	*	*
410	2	*	*	596	*	*
425	2	*	*	1104	*	*
425	2	*	*	1117	*	*
425	1	*	*	380	*	*
425	1	*	*	307	*	*
450	1	*	*	740	*	*
450	1	*	*	809	*	*
450	1	*	*	285	*	*
450	1	*	*	224	*	*
450	1	*	*	989	*	*
450	1	*	*	85	*	*
450	1	8	22	-	-	63

* These specimens fell apart after 2-hr water soak.

PRESS TEMPERATURE

Peanut Hull Waste--The effects of varying temperatures on the material properties are presented in Tables 1-4, 1-16, and 1-18. The possibility of a panel blosing increases with temperature. The temperature range that consistently provided dense, structurally sound panels was 350°F to 400°F. The theory that increased temperature reduces press time was proven ineffective in the section Time Under Pressure. Therefore, 375°F was chosen as the starting point for full scale studies.

Wood Waste--The fact that wood generates more volatiles than peanut hulls results in more possibilities for blowing. Therefore, lower temperatures were evaluated. Tables 1-5 and 1-6 present data for Ponderosa Pine, Table 1-7 for Hard Pine and Tables 1-9 through 1-15 for Douglas Fir. Temperatures from 250°F to 400°F were evaluated. The temperature range that consistently provided dense and structurally sound panels was 300°F to 350°F.

PRESSURE TECHNIQUE

Peanut Hull Waste--For the purpose of this discussion a pressure relief cycle is defined as rapid release, at a predetermined time, of the pressure applied to the material. The press plattens are slightly opened to allow the vapor build up in the material to be released. The pressure is then reapplied and maintained until the press is completely closed. "Decompression time" is a gradual reduction of the final pressure to 0 psi over a predetermined time after the press time selected was complete. Table 1-4 presents a summary of the effects on the properties of 4 inch by 6 inch panels with and without pressure relief cycles. For this size panel and for pressure over 500 psi, the pressure relief cycle improves the properties of the product. This is particularly true where multiple cycles are used. However, the fabrication of the larger panels showed less tendency for blowing without pressure relief (see Tables 1-18 and 1-30 in the section of Full Size Panel Production). This table also presents the effect of "Decompression Time". It appears that a decompression of slightly over one minute will materially improve the product.

Wood Waste--The wood waste small panels, Tables 1-7 through 1-15, show that pressure relief cycles have less effect than that of peanut hulls. The fabrication of the larger panels (see Table 1-33 in the section on Full Scale Panel Production) showed that one pressure relief cycle appears to reduce blowing considerably especially when the release occurs two thirds through the press time. As in peanut hull waste, a decompression time of slightly over one minute will improve the product.

EFFECTS OF POST CURE

The post cure studies were conducted on peanut hull waste. The primary purpose was to determine if the properties of short press time products could be improved. The first effort was an attempt to improve the properties of a 1 minute cure at 450°F. The results are presented in Table 1-19.

TABLE 1-19 EFFECT OF POST CURING CONDITIONS ON PEANUT SHELL PROPERTIES

Press molded 1 minute at 450°F

Specimen	Post Cure Conditions	Wt., grams hrs, H_2O soak 0	 24	Flexural Strength hrs, H_2O soak 0	 24
26-2	1 hr/275°F	*	*	853	
27-1	2 hr/275°F	*	*	659	
28-1	16hr/300°F	*	*	468	
28-2	16hr/300°F	31.9	50.6		113
28-3	16hr/300°F	30.6	49.0		101

* Specimens failed during 2-hr. soak.

There was some improvement in flexural strength compared to those without post cure (Table 1-18) but nothing considered worthwhile. However the resistance to water was improved. It was then determined to examine the effects of post cure on a more conventional processing procedure.

Test panels were fabricated under identical conditions but subjected to various post cure and pre-cure conditions, such as using peanut hulls having two different moisture contents. The pressing conditions of 5 minutes, 500 psi at 375°F were selected because there was a sharper increase in strength beyond 5 minutes which potentially made post cure effects more noticeable, either better or worse. Table 1-20 gives the data from small panels to show changes in dimensions, weight and density for various post cures.

Post cure of the panels indicated definite shrinkage in dimensions, hence volume, weight and density changes. Thickness was the most sensitive to change of the dimensions with weight exhibiting greater changes than volume or density. There seemed to be no correlation in these data. The weight loss is important because this is now considerably greater than the moisture content of the treated hulls prior to processing. This is indicative that water is evolved by a dehydration reaction, probably from a polymerization reaction during pressing. All six panels were next cut into flexural specimens. Five were used for water soaking with one serving as control. Results are shown in Table 1-21. It is seen that the post cure resulted in a definite decrease in percentage weight, volume and density gained on water exposure. The percentage flexural strength loss after 24 hour water immersion was decreased under all post curing condition. Strength increases of over 200% are not realistic and are probably due to a faulty control specimen providing a low flexural strength level.

The above procedure was repeated except that the panels were press cured for only 3 minutes at 375°F and then post cured (see Tables 1-22 and 1-23).

The same effects were found again with post curing causing further decrease in weight, dimensions and density. It appeared that the 3 minute cure resulted in smaller decreases in volume than panels cured for 5 minutes, both were cured at 375°F, while the change in density was larger for the 3 minute cure. This phenomenon is reasonable only if weigh changes are about the same for either cure and this appears to be the case. Overall, however, there appears to be no improvement in properties that would justify a post cure in a production process.

EFFECTS OF PRE-HEAT

This study was conducted with peanut hull waste only. There are several important reasons why the use of preheated, treated peanut hulls is of interest:

a) They can go directly from drying ovens to the press and this would save energy, and permit faster heat-up to desired temperature.

TABLE 1-20 EFFECT OF POSTCURE ON PEANUT HULL PANELS
Moisture Content = 9%; Processed - 5 mins @ 500 psi @ 375°F

Postcure Conditions	No.	Dimensions, cm W	x T	x L	Volume cm^3	Weight grams	Density g/cm^3
None (Control)	1	10.2	0.81	15.2	125.1	116.9	0.96
	2	10.2	0.85	15.3	132.7	116.6	0.88
	3	10.2	0.82	15.2	127.1	115.0	0.90
	4	10.2	0.92	15.2	142.6	117.5	0.82
	5	10.2	0.84	15.2	130.2	117.7	0.90
	6	10.2	0.74	15.2	114.7	120.0	1.05
30 mins/400°F	2	10.1	0.76	15.0	115.1	98.2	0.85
2 hrs/375°F	3	10.0	0.81	15.0	121.5	94.5	0.78
16 hrs/325°F	4	10.1	0.88	15.1	134.2	105.5	0.79
2 hrs /375° + 1hr/425	5	9.8	0.76	14.7	109.5	89.3	0.82
16 hrs/325° + 1hr/ 375°	6	9.9	0.69	14.8	101.1	97.3	0.96

TABLE 1-21 EFFECT OF POSTCURE ON PEANUT HULL PANELS
Moisture Content = 9%; Processed - 5 mins @ 500 psi @ 375°F

Postcure Conditions	% Weight Gain, Hrs Water Soak		% Volume Gain, Hrs Water Soak		% Density Gain, Hrs Water Soak		Flexural Strength, psi Water Soak, Hrs		
	2	24	2	24	2	24	0	2	24
None	28.6	50.0	7.8	23.2	19.8	20.9	748	521	114
30 mins/400°F	6.6	13.7	2.3	4.8	3.7	9.2	421	938	1030
2 hrs/375°F	6.3	11.9	3.1	6.8	3.9	4.7	1254	691	1071
16 hrs/325°F	6.7	20.1	6.1	13.6	1.2	6.4	1239	882	318
2 hr/375° + hr/425°	10.1	21.6	10.0	10.6	0	9.2	901	176	629
16 hr/325° + 1 hr/375°	6.0	13.8	7.0	6.5	0	6.4	1149	927	908

TABLE 1-22 EFFECT OF POSTCURE ON PEANUT HULL PANELS

Moisture Content = 9%; Processed - 3 mins @ 500 psi @ 375°F

Postcure Conditions	No.	Dimensions, cm W	x T	x L	Volume cm^3	Weight grams	Density g/cm^3
None (Control)	1	10.2	0.76	15.2	117.8	120.8	1.03
	2	10.2	0.74	15.2	114.7	121.0	1.05
	3	10.2	0.74	15.2	114.7	119.3	1.04
	4	10.2	0.73	15.2	113.2	119.9	1.06
	5	10.3	1.04	15.3	163.8	127.5	0.78
	6	10.2	0.90	15.3	140.5	126.5	0.90
30 mins/400°F	2	10.1	0.71	15.0	107.6	102.2	0.95
2 hr/375°F	3	10.0	0.73	15.0	109.5	101.5	0.93
15 hr/325°F	4	10.0	0.71	14.9	105.8	96.0	0.91
2 hr/375° + 1hr/425°	5	9.7	0.93	14.5	130.8	84.4	0.65
16 hr/325° + 1hr/ 375°	6	10.1	0.85	15.0	128.8	104.9	0.81

TABLE 1-23 EFFECT OF POSTCURE ON PEANUT HULL PANELS

Moisture Content = 9%; Processed - 3 mins @ 500 psi @ 375°F

Postcure Conditions	% Weight Gain, Hr Water Soak		% Volume Gain, Hr Water Soak		% Density Gain, Hr Water Soak		Flexural Strength, psi Water Soak, hr		
	2	24	2	24	2	24	0	2	24
None	19.1	51.6	4.5	28.7	13.8	9.5	398	69	26
30 mins/400°F	8.0	19.6	3.7	5.7	3.4	12.8	1117	1102	589
2 hr/375°F	7.6	23.1	0	8.4	8.1	13.7	988	494	561
16 hr/325°F	6.5	18.1	1.9	5.9	4.5	11.8	1067	721	519
2hr/375° + 1hr/425°	9.9	33.6	4.6	8.7	6.6	23.9	322	236	259
16/325° + 1hr/375°	7.4	29.2	1.6	8.1	4.8	20.3	650	578	192

b) They can be used to pre-advance the resin to remove a part of the condensation volatiles, thus minimizing blowing tendencies.
c) Achieve more rapid resin flow to improve binder action, thus also minimizing blowing.

After treatment with acid, the peanut hulls were dried to 9% and 3% moisture content and immediately put into sealed containers. Panels were prepared by taking sufficient, 130 grams of peanut hulls, preheating 15 minutes at 400°F, immediately transferring to a preheated mold and pressing.

Using peanut hulls with 9% moisture, data are presented in Tables 1-24 and 1-25 for various press schedules on material preheated 15 minutes at 400°F. It was found that after preheat treatment, the moisture content was in the range of 6.5 - 8.0% water.

The most interesting data are seen in Table 1-25. With press times decreasing, changes in volume and weight vary inversely while strength varies directly with press time regardless of water soaked or not. The above mentioned tests were repeated but using treated peanut hulls having a 3% moisture content. Data are given in Tables 1-26 and 1-27. Again these same trends were found. The best overall performance resulted with the 15 minute cure on material containing 3% moisture before preheat. The data also verified previous results that indicated a minimum press time of 5 minutes at 375°F. Overall, however, the use of a preheat to improve a particleboard made from peanut hulls is apparently effective with longer press cures and is not attractive commercially except for use in very humid or damp environments.

PARTICLE SIZE

Peanut Hull Waste--The effects of particle size became of interest after the first large scale production. Evidence indicated that a high concentration of fine particles can cause blowing because of the following:

a) Fine particles block the escape route of water vapor and volatiles tiles between larger particles.
b) Fine particles can react more rapidly and produce more resinous binder *in situ* and this can then undergo reaction to a higher degree for a given time period, than can coarse particles.

In blown panels, especially those that exploded, it was noticed that dark areas were formed away from edges, where higher degrees of resin formulation had taken place. These dark areas were always found where panels exploded and where there were always considerably more fine particles present. Consistent with this is a cracking phenomenon. Such behavior is consistent with formulation of excess resin ans subsequently more extensive reaction giving off more water (increasing internal pressure) and also causing excessive shrinkage leading to cracking. Shrinkage is rarely seen in 4 inch by 6 inch panels.

TABLE 1-24 USE OF PREHEATED PEANUT HULLS MOLDED AT VARIOUS PRESS CYCLES
Moisture Contact of Treated Material = 9%; Preheat Cycle = 15 min @ 400°F

Press Cycle	Weight Before Preheat	Weight After Preheat	Weight After Pressing	Density g/cm^3
15 min/375°F	130.0	126.6	114.2	1.15
10 min/375°F	130.0	127.4	118.7	1.07
5 min/375°F	130.0	127.7	113.3	1.08
2 min/375°F	130.0	128.6	120.0	0.95
1 min/375°F	130.0	128.0	119.8	0.96

TABLE 1-25 USE OF PREHEATED PEANUT HULLS MOLDED AT VARIOUS PRESS CYCLES
Effect of Water Exposure on Properties

Press Cycle	% Weight Change Water Soak		% Density Change Water Soak		Flexural Strength psi Water Soak		
	2 hr	24 hr	2hr	24 hr	0hr	2hr	24hr
15 mins/375°F	3.8	7.4	0	+2.7	2043	2230	1484
10 mins/375°F	5.3	17.4	2.8	+12.1	1894	1109	458
5 mins/375°F	11.8	39.4	5.8	+14.3	1745	585	76
2 mins/375°F	48.8	66.7	23.6	-3.5	762	27	0
1 min/375°F	33.4	51.1	15.3	-1.0	578	34	0

TABLE 1-26 USE OF PREHEATED PEANUT HULLS MOLDED AT VARIOUS PRESS CYCLES

Moisture Content of Treated Material - 3%; Preheat Cycle = 15 mins @ 400°F

Press Cycle	Weight g Before Preheat	Weight g After Preheat	Weight g After Pressing	Density g/cm^3
15 mins/375°F	130.0	128.0	108.2	1.08
10 mins/375°F	130.0	125.5	111.1	1.11
5 mins/375°F	130.0	128.0	113.1	1.00
2 mins/375°F	130.0	120.4	116.2	0.81
1 min/375°F	120.0	126.4	118.4	0.81

TABLE 1-27 USE OF PREHEATED PEANUT HULLS MOLDED AT VARIOUS PRESS CYCLES

Effect of Water Exposure on Properties

Moisture Content of Treated Material = 3%; Preheated Cycle = 15 min @ 400°F

Press Cycle	% Weight Change Water Soak		% Density Change Water Soak		Flexural Strength, psi Water Soak		
	24 hrs	24 hrs	2 hrs	24hrs	0hrs	2hrs	24hrs
15 mins/375°F	4.1	8.3	1.8	0.9	2080	1257	1211
10 mins/375°F	4.6	10.6	1.9	8.4	2059	1632	816
5 mins/375°F	11.1	16.1	6.9	12.3	929	1422	1311
2 mins/375°F	31.1	57.0	18.0	16.1	1106	126	44
1 min/375°F	65.2	63.7	25.6	29.3	613	0	43

For all future work it was decided to remove any material that would pass through a -32 to -42 Taylor Screen. Also it was decided to mix all material thoroughly in order to insure a random particle size.

Wood Waste--The initial work on Douglas Fir was on a hammermilled material where the particle sizes ranged from -6 to 14 mesh. Results are presented in Tables 1-8 through 1-10. The final work was done with commercial wood waste. Table 1-11 presents results with particles less than 17 mesh and Table 1-12 presents results with particles greater than 17 mesh. As with the peanut hull waste, the large particles provided a better product.

FULL SIZE PANEL PRODUCTION

Peanut Hull Waste--Panels were nominally fabricated at the Washington State University's facility, 50 inch by 50 inch by 0.50 inch thick and 12 inch by 15 inch by 0.50 inch thick. The 50 inch by 50 inch panels were molded in an oil heated press and the 12 inch by 15 inch panels in an electrically heated press. Stops were used to control final board thickness.

The mat was formed by hand in a deckle box, Figure 1-1, on a sheet of Mylar placed on an aluminum caul plate. A heavy board was placed on the mat in the deckle box with the frame and board removed (Figure 1-2). The mat was covered on top by Mylar film, Figure 1-3, and an aluminum caul plate, Figure 1-4. The entire assembly, except for the particle board base, was slid into the press (Figure 1-5) and pressure applied (Figure 1-6). For the small panels, a single steel caul plate was used in the bottom of the mat without Mylar film. A steel wear plate mounted on the bottom of the top press plate was in contact with the top of the mat during pressing. No sticking was encountered without Mylar.

All boards, except one, that remained intact were tested for modulus of rupture (MOR) which is also called flexural strength, and internal bonding (IB) according to ASTM-D-1037 "Standard Methods of Evaluating the Properties of Wood Base Fiber and Particle Panel Materials". Some modulus of elasticity (MOE) were also determined. Figure 1-7 shows the test specimen cut up pattern of the intact panels evaluated. Portions of some of the "blown" panels were also treated. The results of the pressing operations are given in Tables 1-28A and B for large panels.

The processing variables study, described in the previous text, gave excellent indication of problems and approximate processing requirements. This work was conducted with small (4 inch by 6 inch) specimens. Fabrication of panels whose areas and volumes were 78 and 312 times greater, respectively, needed some changes in moisture content. Rather than use moisture contents of 7% to 13% the first material was dried to about 6% as used for wood particles in the particle board industry. Temperatures, pressures and press times were as determined on small panels except that a decompression time of 3 minutes was used for the large panels.

A wide variation in physical and mechanical properties was found. Three panels were good and eight exploded during decompression, all boards had

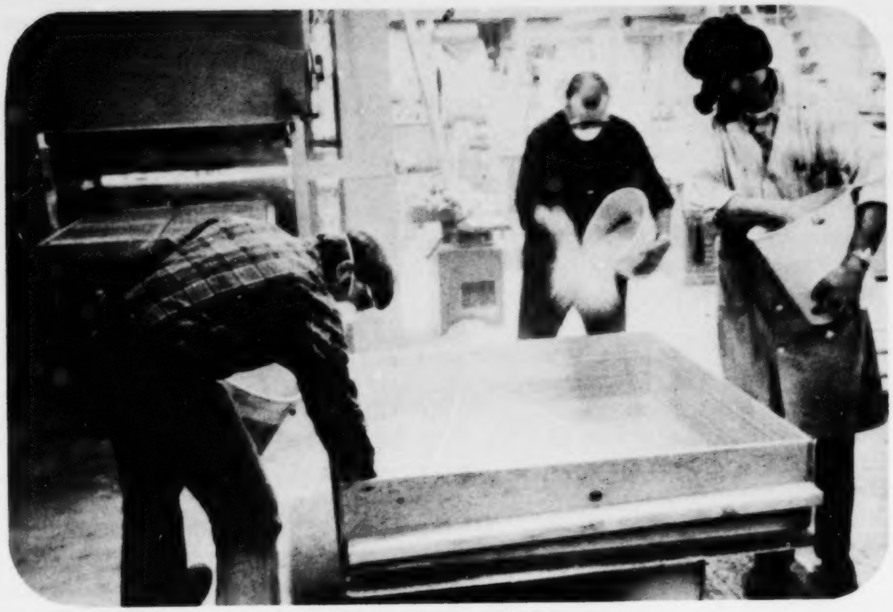

Figure 1-1. Forming mat.

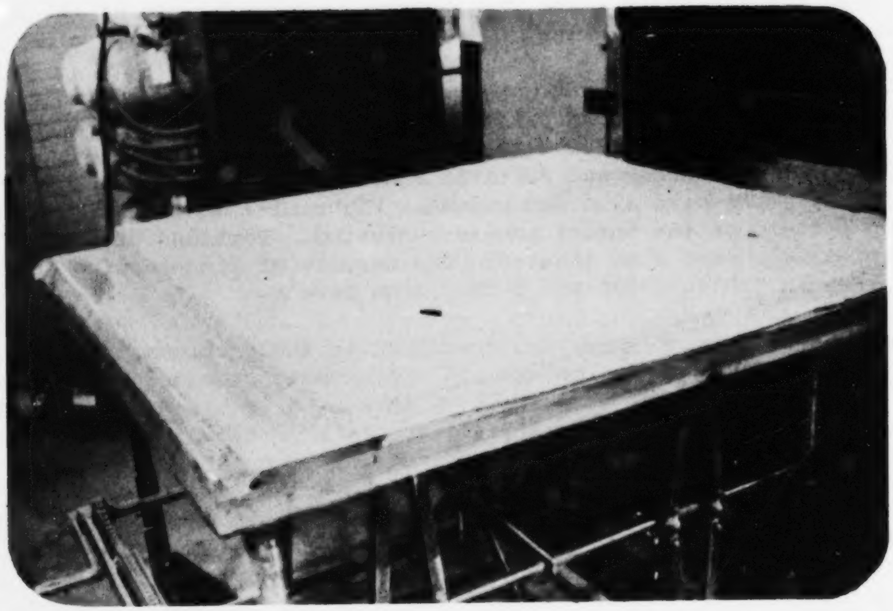

Figure 1-2. Placing board on mat.

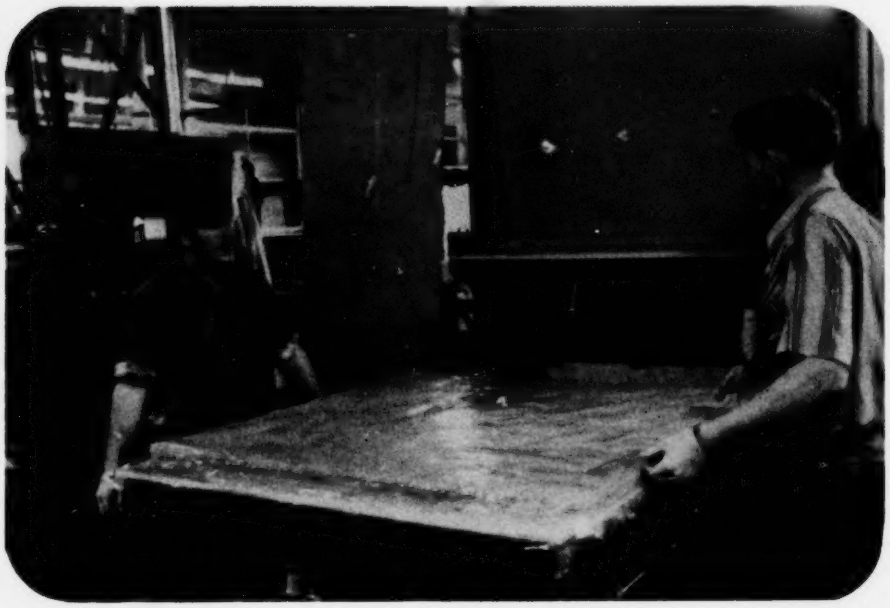

Figure 1-3. Covering with Mylar.

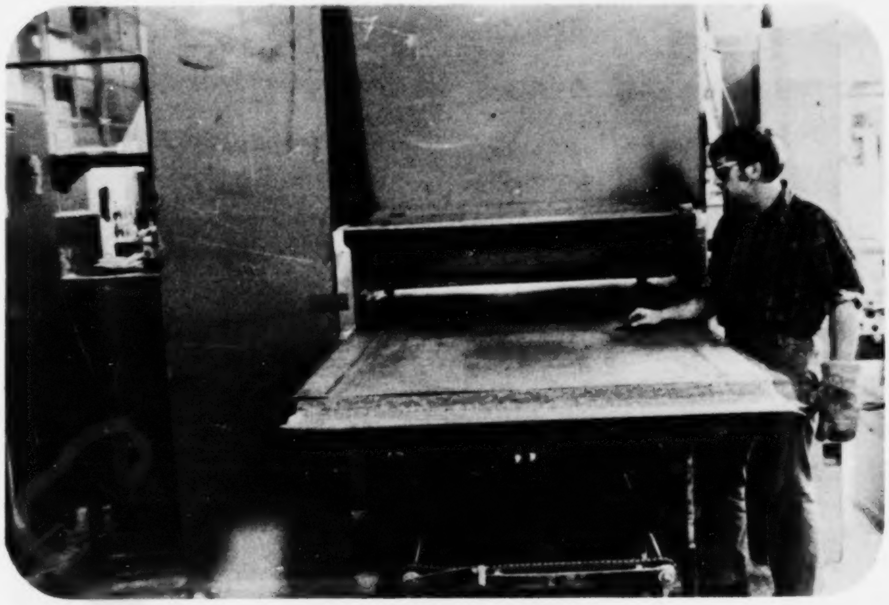

Figure 1-4. Placement of aluminum caul plate.

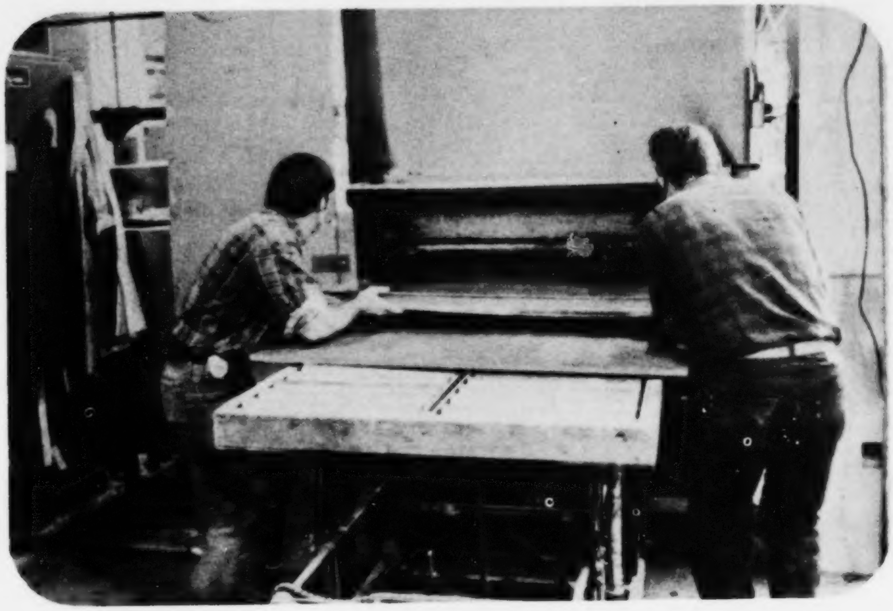

Figure 1-5. Insertion into press.

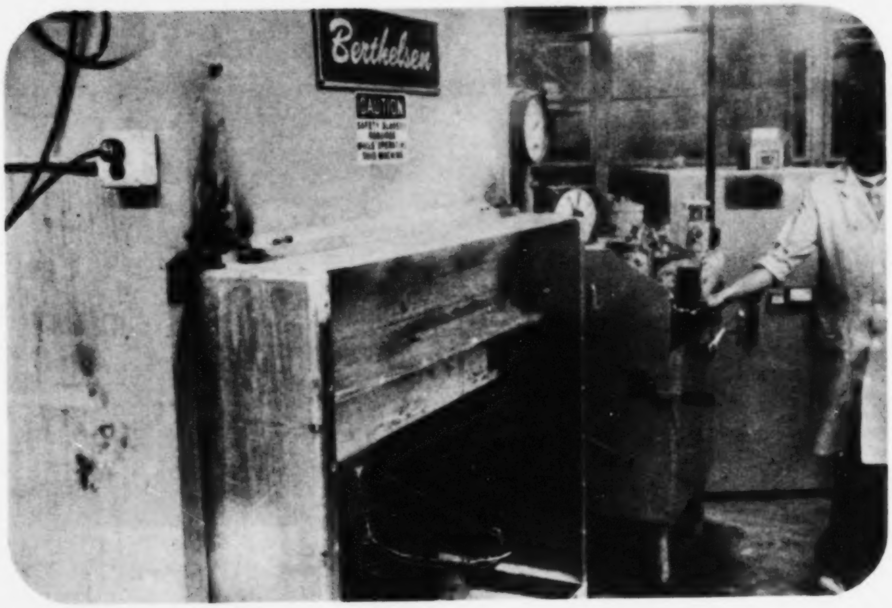
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Figure 1-6. Molding.

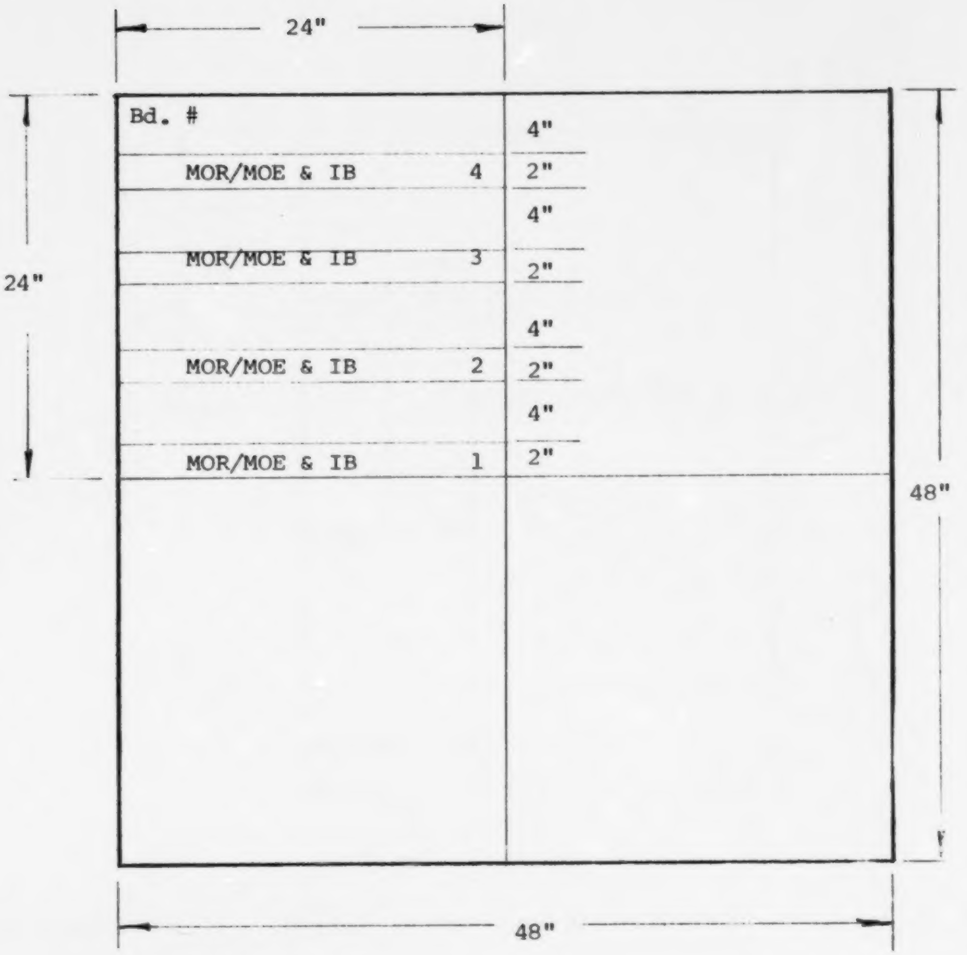
24"
24"
Bd. #
4"
MOR/MOE & IB 4
2"
4"
MOR/MOE & IB 3
2"
4"
MOR/MOE & IB 2
2"
4"
MOR/MOE & IB 1
2"
48"
48"

Figure 1-7. Test specimen cut-up diagram. 50 BY 50 INCH PANELS.

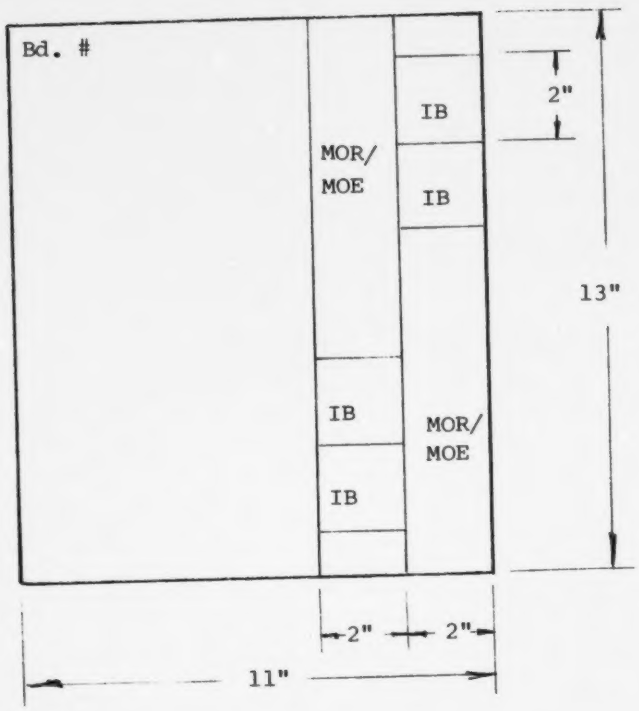
Bd. #
MOR/
MOE
IB
IB
2"
13"
IB
IB
MOR/
MOE
2"
2"
11"

Figure 1-7. (Continued) Test specimen cut-up diagram. 12 BY 15 INCH PANELS.

TABLE 1-28A PRESSING CONDITIONS AND AVERAGING PHYSICAL PROPERTIES OF THE 50 BY 50 IN. PANELS

Board No.	Furnish MC (%)	Weight Furnish Used, lbs	Press Temp (°F)	Press Time (min)	Press Pressure psi	Comments
(B) 1	5.5	60	375	5+3[*]	500	Did not reach stops, good board
2	8.5	51	375	5+3	500	Reached stops board blew @ loops
3	4.8	51	375	5+3	500	Reached stops good board
(A) 4	5.9	51	375	5+3	500	Board Blew
5	4.6	47	375	5+3	500	Board blew at 100 psi
6	4.6	47[+]	375	7+3	500	Reached stops, board blew
7	4.2	47	375	5+3	700	Reached stops, board blew @ 40 psi
(B) 8[‡]	5.5	47	375	5+3	500	Board blew (blistered)
9	5.7	42[#]	375	5+3	500	Reached stops, board blew
10	6.8	42	375	5+3	500	Reached stops, board blew
(A) 11	5.9	42	375	5+3	500	Reached stops, good board

[*] Five minutes under pressure, three minutes for decompression.

[+] Thermocouple study. Put down 23.5 lb hulls, put in Thermocouples and and added remaining 23.5 lb of hulls.

[‡] Five minutes under pressure, three minutes for decompression.

[#] Thirty-two material screened out.

TABLE 1-28B PRESSING CONDITIONS AND AVERAGING PHYSICAL PROPERTIES OF THE 50 BY 50 IN. PANELS

Board No.	Internal Bond		Modulus of Rupture and Modulus of Elasticity		
	SG	PSI	SG	MOR (psi)	MOE (psi x 10^6)
(B) 1	0.96	49	1.02	710	-
2	1.06	193	1.03	1550	-
3	0.91	146	-	-	-
(A) 4	1.10	-	-	-	-
5	-	-	-	-	-
6	-	-	-	-	-
7	-	-	-	-	-
(B) 8 *	0.98	128	0.96	1260	-
9	0.89	14	-	-	-
10	0.87	103	0.86	900	0.236
(A) 11	0.88	101	0.89	940	0.567

* Five minutes under pressure, 3 minutes for decompression.

blisters or severe shrinkage cracks. Portions of the blown panels, such as in No. 2, that remained intact had rather high internal bond values and the best modulus of rupture value of all the large panels. All the blowing problems occured during pressure release after the press cycle.

The blowing phenomenon is caused by excessive vapor pressure in the panel during the press cycle. This vapor pressure emanates from water and/or other vaoltile materials. Water can come from that already present in the peanut hulls after processing or from the resinous binder being formed in situ from pentoses. This involves a cyclodehydration reaction in which 36% of the pentose molecule is evolved as water. This is a large amount to be given off and occurs during the press cycle under elevated temperatures. To give some idea of potential internal vapor pressure (due to water) during press cure, the following table was taken from the Handbook of Chemistry and Physics, Steam Tables:

Temp. °F	Pressure, psi
200	11.5
250	29.8
300	67.0
350	134.6
375	184.3
400	247.2

To determine relative stream pressures generated during cure, thermocouples were embedded into the mat and temperature recorded during cure. The resulting temperatures are shown in Figure 1-8. It is obvious that vapor pressure within the board easily exceeds that of the internal bond strength of the panels. This is particulary so in a hot panel and even more so in this study where the resin matrix is thermoplastic at this temperature. Commerical particle board is at high and low moisture contents in the hulls. Blowing with a high (8.5%) moisture content is understandable but blowing with a 4.2% moisture content is unusual to say the least. One explanation is that low moisture content made for more difficult resin flow due to insufficient plasticizing action. However, evidence indicates that particle size causes blowing also because of the following:

a) Fine particles block the escape route of water vapor and volatiles between larger particles.
b) Fine particles can react more rapidly and produce more binder in situ. This binder can then undergo reaction to a higher degree for a given time period than can coarse particles.

In the blown panels, especially those that exploded, it was noticed that dark areas were formed away from edges, where higher degrees of resin formation had taken place. These dark areas were always found where panels exploded and where there were always considerably more fine particles present. Consisten with this is a cracking phenomenon clearly seen in Figure 1-9. The crack is 0.75 inches wide and note the dark area around the crack. Such behavior is consistent with formation of excess resin and subsequently more extensive reaction giving off more water (increasing

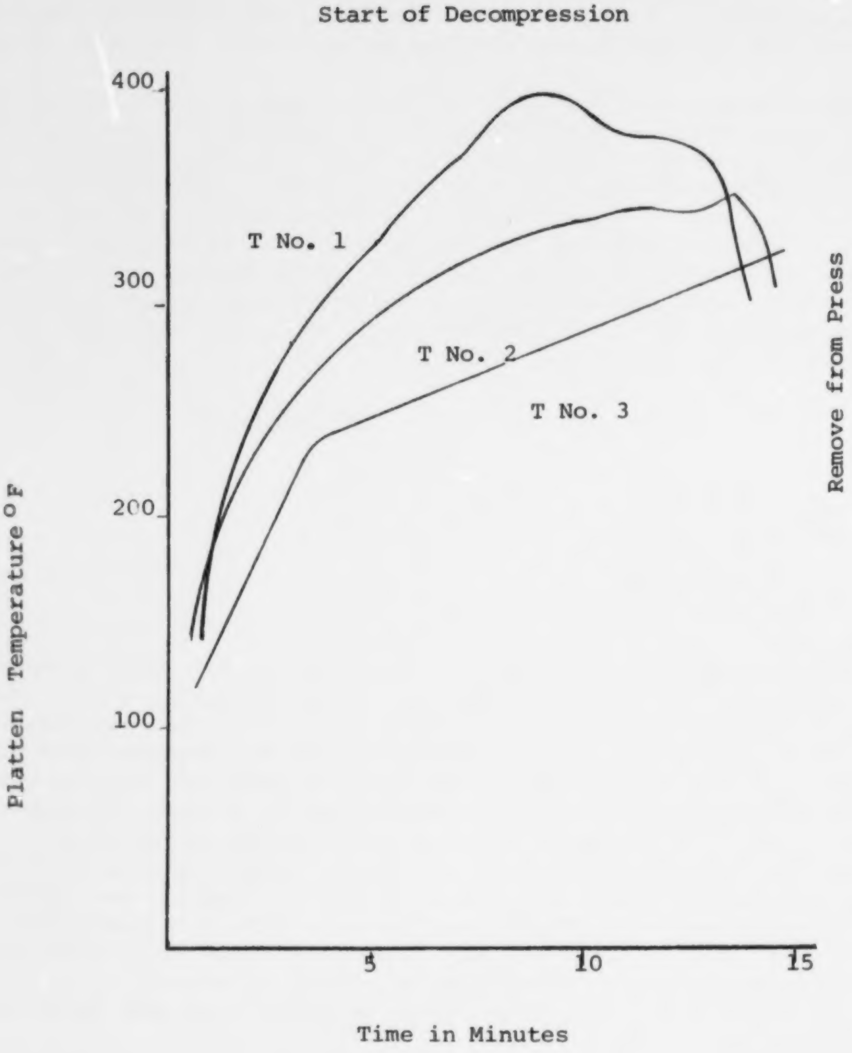

Figure 1-8. Internal panel temperature.

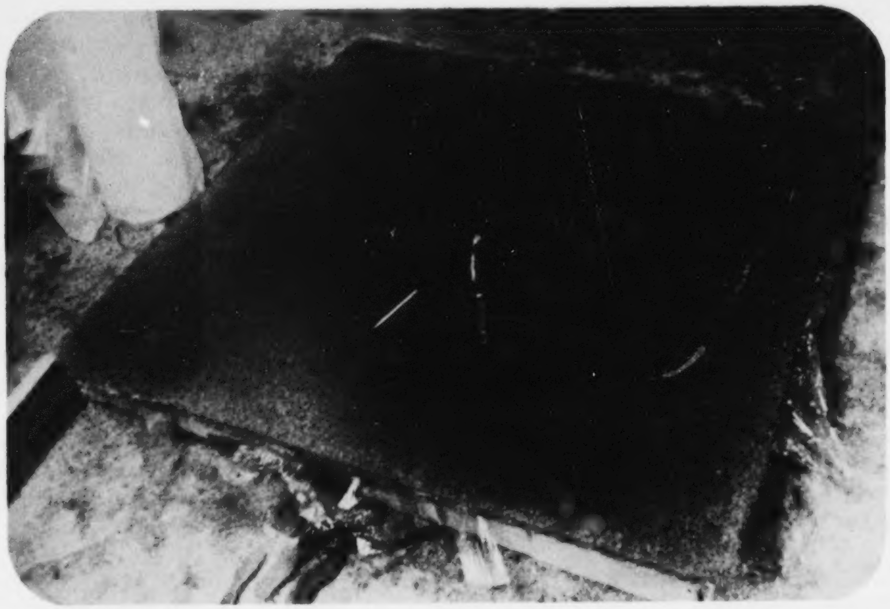

Figure 1-9. Cracking phenomenon.

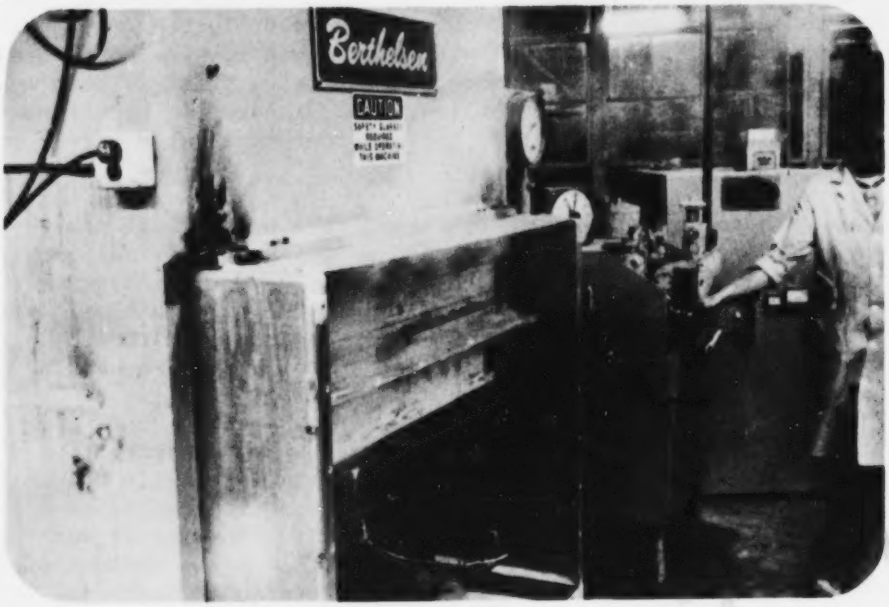
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Figure 1-10. Steam generation.

internal pressure) and also causing excessive shrinkage leading to cracking. This meant that another, and unknown variable, was operative during the first 9 panels and could be the reason why panel No. 8 was unsuccessful even though it was a duplicate of No. 1 in all other respects. The processed material, as received by Washington State University, was not mixed or randomized as is normal procedure. Consequently there could be major variations in particle size distribution in the various drums. Once this parameter appeared to be a factor, examination of individual drums revealed large differences in the amount of fines in various drums.

In the next dull size study, the entire material was pre-screened to remove the -32 to -42 material. Figures 1-10 and 1-11 show steam evolution shortly after the press cycle starts and near the end of the decompression cycle, where blowing occurs. Figures 1-12 and 1-13 show removal of a successful panel from the press. Figure 1-14 shows a 50 inch by 50 inch panel cooling anf Figure 1-15 is that of a 24 inch by 24 inch specimen cut from the larger panel. Figure 1-16 shows where a panel exploded while in the press. Figure 1-17 was taken from a wall 40 feet distance from the press, showing debris from an explosion while Figure 1-18 shows one segment of panel hurled about 30 feet from the press.

The curves in Figure 1-8 are interesting for other reasons. They show that the peripheral regions of the panel never exceeded 300°F at the end of the press cycle. Since volatiles can escape more readily near edges of panels, the cooling effect is greater and the absence of insulation around the panel permits greater heat loss to the environment. The shape of curve 3 shows no sudden drop in temperature as in curves 1 and 2. This suggests that the sudden drop in temperature is caused by the sudden evolution of vapors (cooling) as occurs just prior to blowing (increased hissing noise heard prior to explosions). All this suggests the use of a "hotter" acid system to permit resin formation occuring at lower temperatures to permit more strength development in the periphery while also reducing the stream pressure in the panel.

Upon reviewing these data we became concerned that peanut hull waste composites would not meet the 2400 psi modulus of rupture (flexure) requirement for structural qualification because of the lack of reinforcement with the slenderness ratio of a fiber. Therefore, on the next full-scale test it was decided to make a peanut hull panel conventionally with a urea resin to determine if the reinforcement theory was correct. The results of this evaluation are presented in Table 1-29.

The peanut hull furnish was prepared at Material Systems Corporation (see section on Type and Percent of Acid Absorbed by the Material - Peanut Hull Waste and Table 1-3). The furnish was post dried to between 1.5 and 8% moisture content and screened to all -20 material. The work at Washington State University was started with 4 inch by 6 inch panels, Table 1-4, to develop the previously discussed process parameters. The next step was to fabricate 12 inch by 15 inch panels, Table 1-5, to further refine the process.

For the purposes of this discussion a pressure relief cycle or a "bump

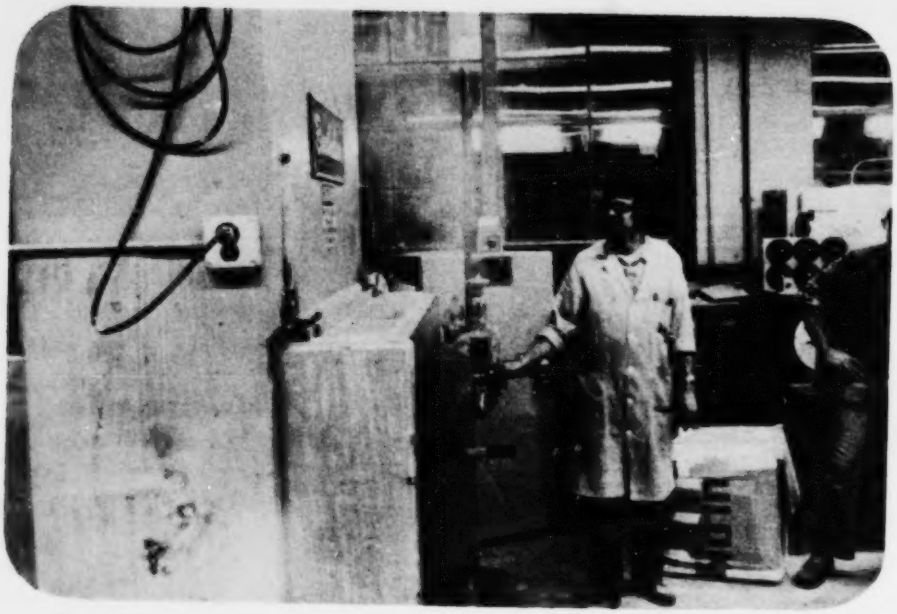


Figure 1-11. Steam generation.

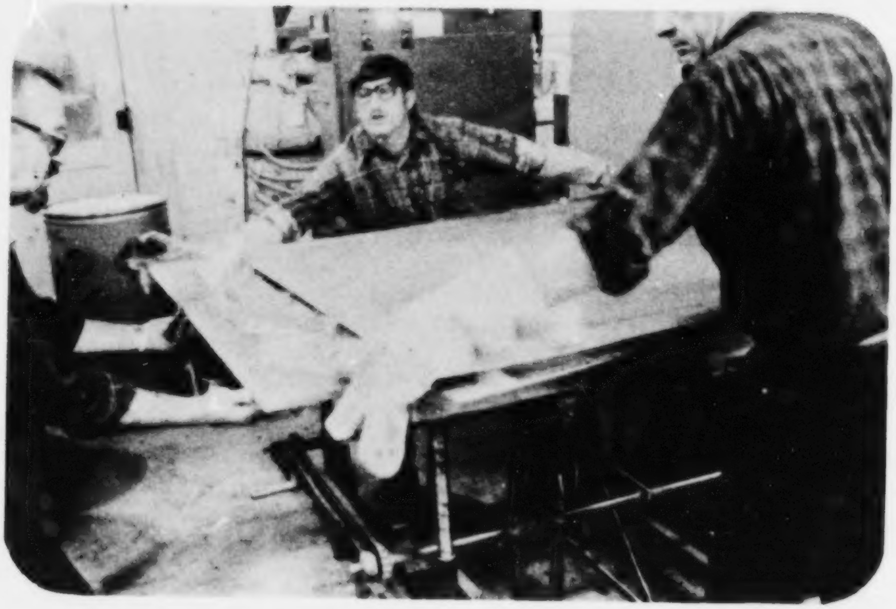


Figure 1-12. Panel removal.

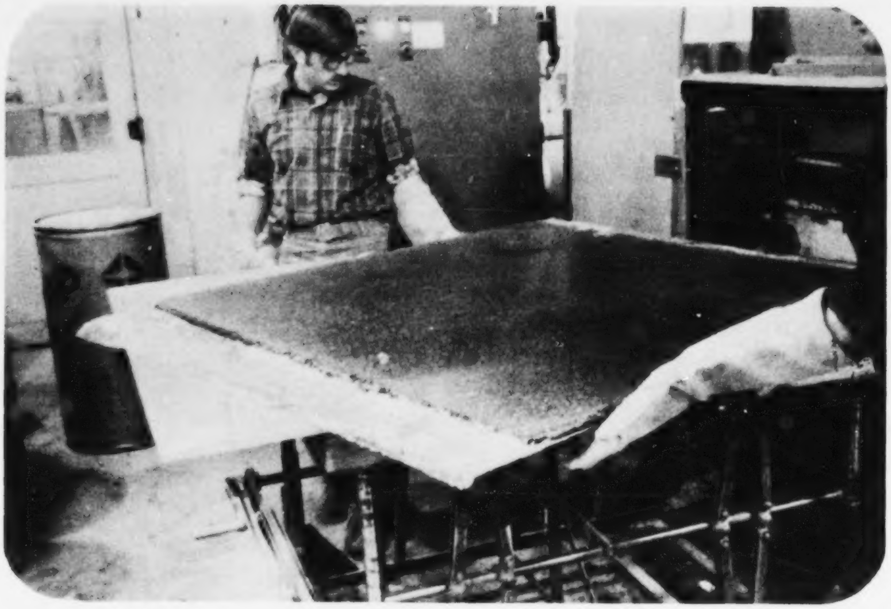


Figure 1-13. Panel removal.

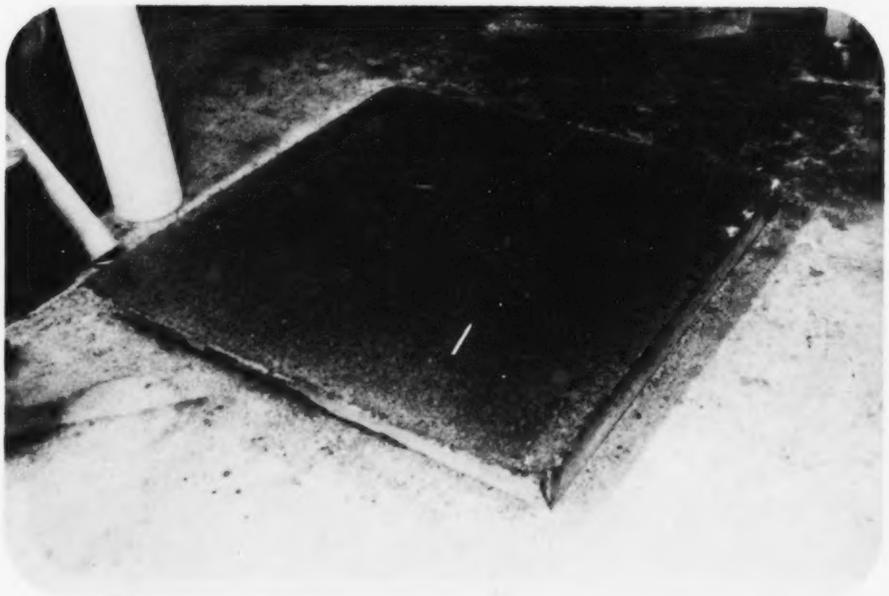


Figure 1-14. Panel cooling.

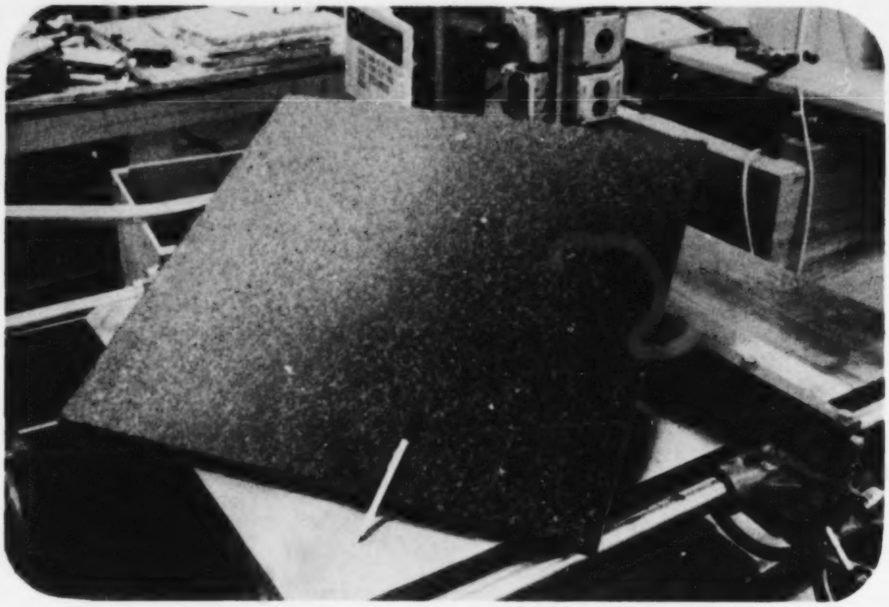


Figure 1-15. Section cut for test.

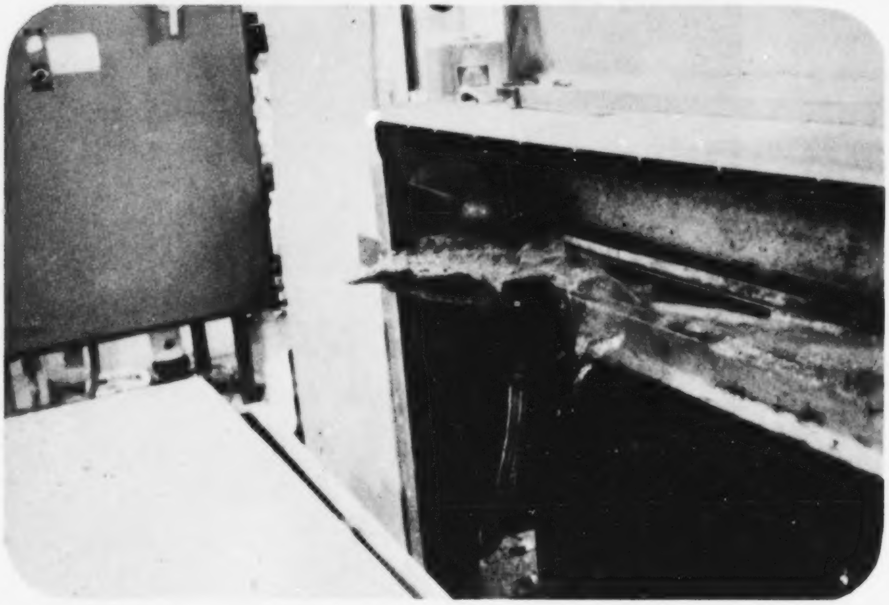


Figure 1-16. Panel explosion.

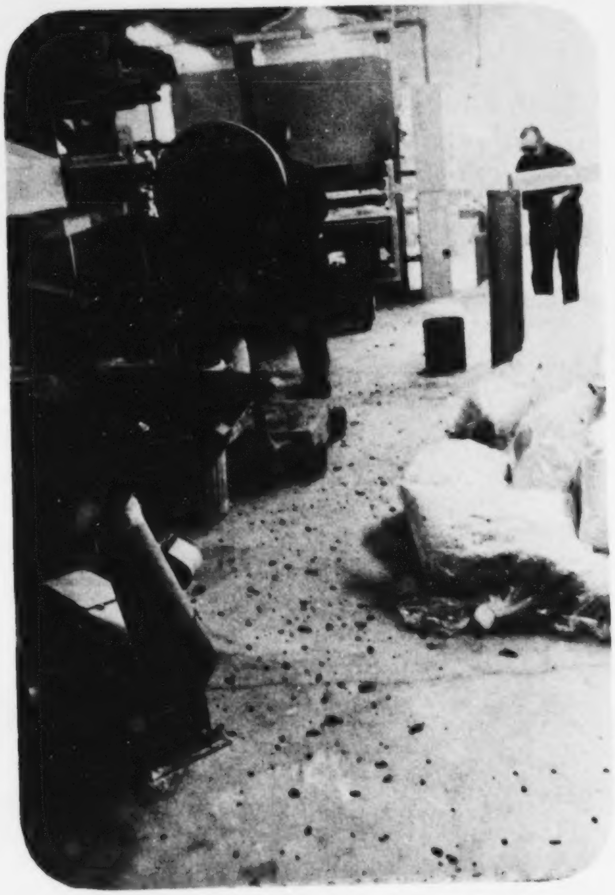


Figure 1-17. Debris from explosion.

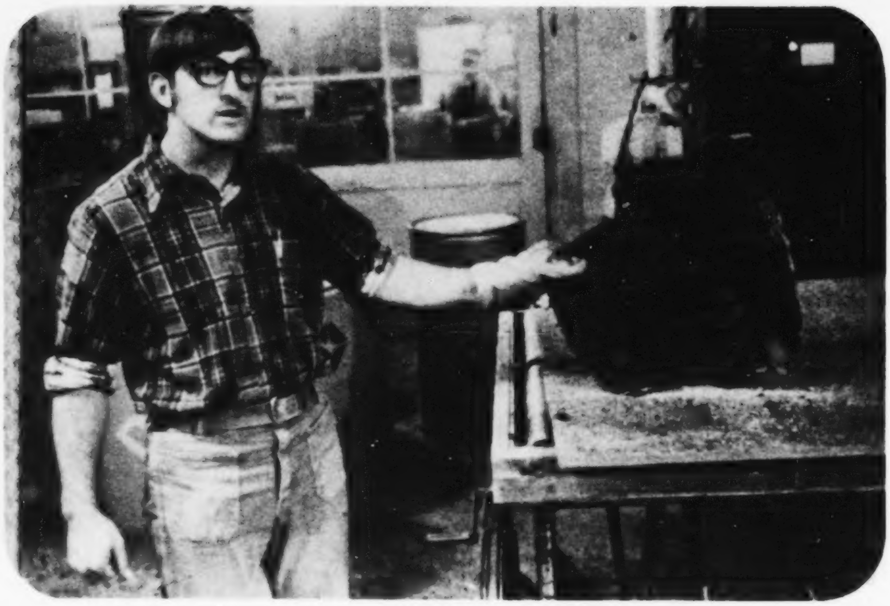
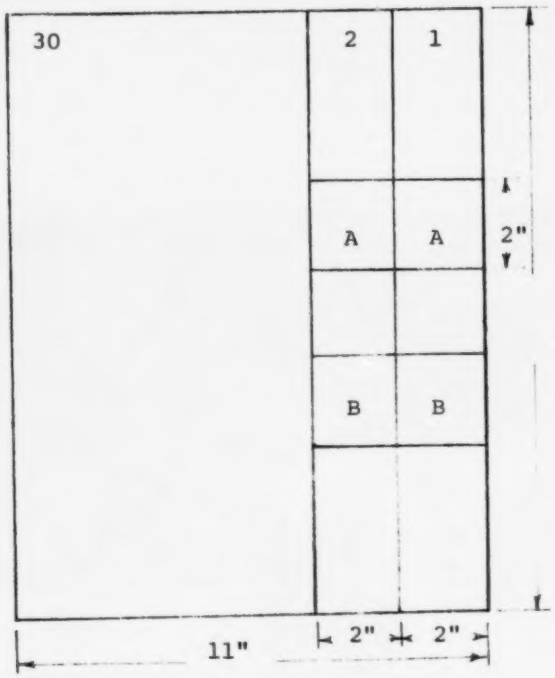


Figure 1-18. Segment of exploded panel.

TABLE 1-29 CUT UP DIAGRAM AND PHYSICAL TEST RESULTS OF BOARD MADE WITH UREA FORMALDEHYDE RESIN (PEANUT HULL FURNISH)



MOR/MOE

Spec No.	SG	MOR (psi)	MOE (psi x 10^{-6})
1	0.81	1100	0.270
2	0.81	1148	0.278

INTERNAL BOND

Spec No.	SG	PSI
1-A	0.81	115
1-B	0.81	122
2-A	0.81	122
2-B	0.81	122

cycle" can be defined as rapid release, at a predetermined time, of the pressure applied to the mat. The press plattens were slightly opened to allow the vapor build up in the mat to be released. The pressure was then reapplied and maintained until the press was completely closed. "Decompression time" is a gradual reduction of the final pressure to 0 psi over a predetermined time, after the press time selected was complete.

The closing pressure for each board was selected before pressing. This pressure was reached within 0.5 minutes after pressing was begun. Once the target pressure was obtained an additional 100 psi was added and the pump turned off. As compression of the mat continued the pressure decreased. This pressure drop was allowed to reach 100 psi lower than the target pressure. At this point the pump was started and the pressure returned to the 100 psi above the target and the procedure repeated. Once the press was closed (on stops) the pressure was reduced to about 200 psi in approximately 3 minutes and this pressure then held for any remaining time.

Board making data are presented in Tables 1-30 and 1-31 for the peanut hull furnish. The tables are divided into runs depending on the board size made.

Table 1-30, covering the hammermilled peanut hulls, shows a trend from run to run towards pressing conditions that are quite close to what might be desired for making successful boards. Runs 5 and 7 indicate that conditions are straddling the borderline between blown and intact boards. More investigation should be carried out to determine exactly what the optimum condition would be. Table 1-31 presents the processing parameters for a peanut hull waste panel fabricated with conventional processing techniques.

Each run will be briefly discussed below:

Run 1: Pressing at a relatively long press time (7 to 15 minutes), with and without a bump cycle and without a decompression cycle caused blows in all boards.
Run 2: A change from the 12 by 15 inch press to the 50 by 50 inch press for this run created the same problem as noted in Run 1. The addition of a two minute decompression cycle for Board 9 also resulted in a blow. A variation in the bump cycle was also introduced with Board 9.
Run 5: Board number 25, pressed with a nine minute press time, no bump cycle and a two minute decompression cycle, blew. Reduction in the press time to four and five minutes, increased pressure to insure closing of the press, elimination of the bump cycle and the addition of a 1.25 minute decompression cycle, yielded six intact boards and five blow boards. It appears that this combination is in the "fringe" area of making successful boards of this material and binder. It is quite encouraging, at this point, to note the number of intact panels made. A further effort to concentrate on optimizing the conditions should be carried out.
Run 7: Board number 44, which was pressed for 3.5 minutes at 375°F, produced a severe blow during the decompression cycle. This blow occurred when the pressure was reduced to 30 psi. Previous blows all occurred at a pressure of 100 psi or less. Reducing the press temperature to 355°F and keeping all other conditions the same appeared to be acceptable.

TABLE 1-30 BOARD-MAKING CONDITIONS FOR PEANUT HULL FURNISH

Board No.	Weight Formed	MC (%)	Temp (^{o}F)	Time (min)	PSI	Thick-ness in.	Density	Board Conditions
Run 1 - 0.5 x 12 x 15" Boards								
1	1900g	5.5	375	7	1000	-	-	Blown, no bump
2	1900g	5.5	375	10	1000	-	-	Blown, bump at 5 min, did not reach stop
3	1900g	5.5	375	15	1000	-	-	Blown, bump at 5 & 10 min, pop at 10 min
4	1900g	5.5	390	10	1000	-	-	Blown, bump at 5 min, close at 7 min
5	1800g	5.5	390	10	1000	-	-	Blown, bump at 5 min, close at 6 min
6	1800g	5.5	390	15	1000	-	-	Blown, bump at 5 & 10 min, close at 5.5 min
Run 2 - 0.5 x 50 x 50" Boards								
7	55 lbs	5.5	390	10	1000	0.55	-	Blown, bump at 3 & 7 min, blow at 7 min
8	55 lbs	5.5	390	10	1000	-	-	Blown, bump at 2 & 5 min, blow at 5 min
9	55 lbs	5.5	375	10	1000	0.45	1.01	Blown at 100 psi, bump at 3 min, hold open for 2 min, back to pressure at 5 min
Run 5 - 0.5 x 50 x 50" Boards								
25	51 lbs	5.7	375	9	800	0.47	1.09	Blown, close at 7 min
26	51 lbs	5.7	375	4	1200	0.56	.92	Intact/blister, close at 3.5 min
27	51 lbs	5.7	375	5	1200	0.53	1.07	Intact/blown, close at 3.5 min
31	51 lbs	5.7	375	5	1200	0.50	1.03	Blown, close at 3.5 min
32	51 lbs	5.7	375	4.5	1200	0.55	0.98	Blown, close at 3 min
33	51 lbs	5.7	375	4	1200	0.56	0.93	Intact, close at 3 min
34	51 lbs	5.7	375	4	1200	0.57	0.89	Intact/blister, close at 3 min.
35	51 lbs	5.7	375	4	1200	0.55	0.93	Blown, close at 3 min
36	51 lbs	5.7	375	4	1200	0.51	1.01	Intact/blister, close at 3 min.
37	51 lbs	5.7	375	4	1200	0.53	0.94	Blown, close at 3 min
38	51 lbs	5.7	375	4	1200	0.52	1.01	Intact/blister, close at 3 min
39	51 lbs	5.7	375	4	1200	0.56	0.92	Blown, close at 3 min

(continued)

Table 1-30 (Continued) BOARD-MAKING CONDITIONS FOR PEANUT HULL FURNISH

Board No.	Weight Formed	MC(%)	Temp (°F)	Time (min)	PSI	Thick-ness in.	Density	Board Conditions
Run 7- 0.25 x 50 x 50" Boards								
44	25.5lbs	5.7	375	3.5	1200	0.24	-	Blow at 300 psi, close at 1.5 min
45	25.5lbs	5.7	355	3.5	1200	0.33	0.84	Intact/blister, warp, close at 1.5 min
46	25.5lbs	5.7	355	3.5	1200	0.28	0.97	Intact/blister, warp, close at 1.75 min
47	25.5lbs	5.7	355	3.5	1200	0.32	0.82	Intact/warp, close at 2 min.

TABLE 1-31 BOARD-MAKING CONDITIONS FOR PEANUT HULL FURNISH WITH UREA RESIN
Run 10 - 0.5 x 12 x 15 in. boards treated peanut hulls with 6% urea resin added
(Board pressed at a SG of 0.72)

Board Number	Weight Formed	MC (%)	Temp (°F)	Time (min)	PSI	Closing Time (min)	Board Condition
28	1200g	7.3	325	5	500	1	Intact
29	1200g	7.3	325	5	500	1	Intact
30	1200g	7.3	325	5	500	1	Blown

Table 1-32 presents the results of the tests for modulus of rupture, modulus of elasticity, and internal bond according to the American Society for Testing and Materials Standard D-1037, "Standard Methods of Evaluating the Properties of Wood-Base Fiber and Particle Panel Materials". These results indicate superior properties to that of a conventional process (Table 1-29) with peanut hull waste. It is believed that the reinforcing theory holds. Although the economics (discussed in the section Economics) is acceptable, the strengths are less than the required 2400 psi modulus of rupture. This makes the board acceptable for non-structural applications but not qualifiable under structural codes.

Wood Waste--The Douglas Fir wood waste was treated with p-toluene sulfonic acid at Washington State University in a commercial blender. The furnish was dried to between 1.5% and 8% moisture content and screened to remove all -20 mesh particles. The initial work was done on 4 inch by 6 inch panels. This data is presented in Tables 1-11, 1-12, and 1-13. The processing information developed was used to produce 12 inch by 15 inch panels. This data is presented in Tables 1-14 and 1-15.

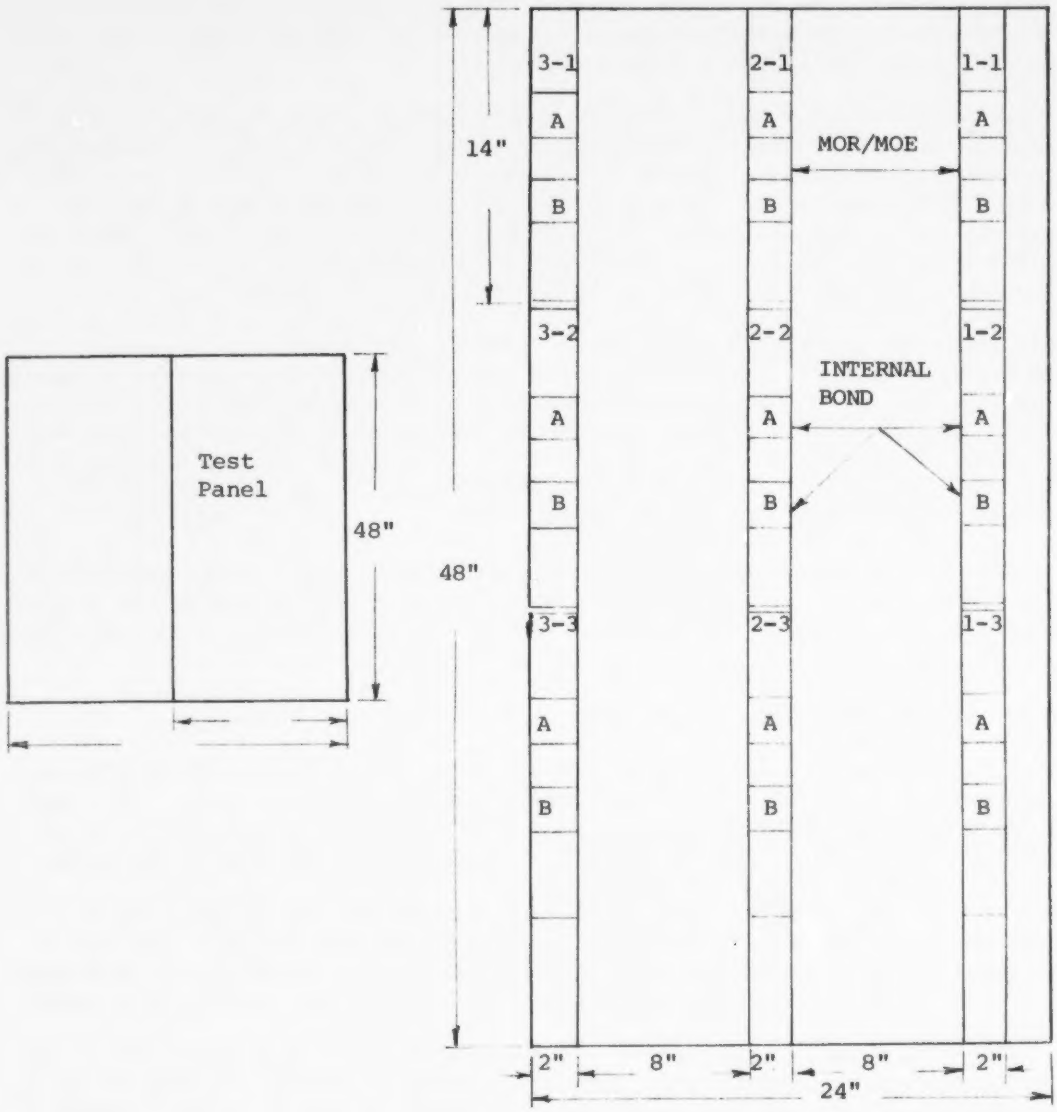
The material was formed into mat and pressed, as described for peanut hull waste in the preceeding section. Table 1-33 presents the board-making data for Douglas Fir. This table summarizes the variations that were tried. These included three binder treatments, combinations of binder treatments, a range of moisture contents from 1.5 to 7.8%, press temperatures of 300°F to 390°F, press times of six to fourteen minutes, bump and no-bump cycles and 0 to 2.5 minutes of decompression time.

By the end of Run 9, the proper conditions for pressing were being approached. Only one of the final eight 0.5 by 50 by 50 inch boards blew. The cause of this blow is not known as it was pressed under the same conditions as the others.

The various runs using Douglas Fir will be discussed below:

Run 3: Preliminary work with 0.5 inch thick by 12 inch by 15 inch boards was conducted to get a "feel" for how the material would react. The wire screen mentioned under notes for Boards 19, 20, and 22 was placed on top of the mat in an attempt to provide vent passages. However, other combiin the production caused blows.
Run 4: 0.5 inch thick by 50 inch by 50 inch boards were made with a combination of binder treatments. Board 23, pressed at 300°F for seven minutes produced an intact panel even though the press did not completely close. Board 24, with the addition of one minute press time and a higher pressure to close the press, blew.
Run 6: The moisture content of the furnish was increased from 3% to 7.8% in an attempt to improve the plasticity of the material. Boards 40 to 41, pressed at 325°F, did not reach the desired thickness and blew. Boards 42 and 43 were pressed at 340°F. The desired thickness was reached; however, blows still occurred.
Run 8: In this run the board thickness was reduced from 0.5 inch thick to 0.25 inch thick. Three binder treatments, two moisture contents, two press

TABLE 1-32 CUT-UP DIAGRAM AND PHYSICAL TEST RESULTS FOR BOARD 27 (PEANUT HULL FURNISH)



Test Panel
48"
48"
14"
3-1
2-1
1-1
A
B
MOR/MOE
3-2
2-2
1-2
INTERNAL BOND
3-3
2-3
1-3
2"
8"
2"
8"
2"
24"

(continued)

TABLE 1-32 (Continued) CUT-UP DIAGRAM AND PHYSICAL TEST RESULTS FOR BOARD 27 (PEANUT HULL FURNISH)

MOR/MOE

Spec No.	SG	MOR (psi)	MOE (psi x 10
1-1	0.97	1427	--
1-2	0.96	1351	0.397
1-3	--	--	--
2-1	0.89	597	0.166
2-2	0.01	1329	0.373
2-3	0.98	1410	0.363
3-1	0.93	918	0.277
3-2	1.06	1433	0.404
3-3	--	--	--

Internal Bond

Spec No.	SG	PSI
1-1A	0.92	59
1-1B	1.00	105
1-2A	0.99	158
1-2B	1.00	155
1-3A	0.99	156
1-3B	1.00	152
2-1A	0.88	44
2-1B	0.87	37
2-2A	1.04	169
2-2B	1.03	197
2-3A	0.96	163
2-3B	1.01	177
301A	0.89	44
3-1B	0.93	53
3-2A	1.04	179
3-2B	1.05	204
3-3A	1.05	223
3-3B	1.08	238

TABLE 1-33 BOARD-MAKING CONDITIONS FOR DOUGLAS FIR FURNISH

Binder Number	Weight Formed	MC (%)	Temp (°F)	Time (min)	PSI	Thick-ness	Density	Decom-pression Time	Comments
Run 3 - 0.5 x 12 x 15 in. boards									
10	1800g	1.5	390	12	750	-	-	0	Blown, bump at 7 min increase to 1500 psi, did not close
11	1800g	1.5	390	12	1100	-	-	0	Blown, bump at 7 min increase to 1500 psi, did not close
12	1600g	1.5	390	12	1100	-	-	0	Blown, bump at 7 min, did not close
13	1600g	5.5	390	12	1100	-	-	0	Intact, bump at 7 min, close at 5.5 min
14	1600g	3.0	300	5	1000	-	-	0	No bump close at 4.5 min
15	1600g	3.0	300	6	1000	-	-	-	Stuck to platten, close at 5.5 min.
16	1600g	3.0	300	9	750	-	-	-	Close at 7 min
17	1600g	3.0	300	14	750	-	-	-	Blow at 14 min 750 psi
18	1600g	3.0	300	10	1000	-	-	2.5	Blown, close at 7.5 min
19	1600g	3.0	300	10	1000	-	-	2	Blown, wire screen on top, did not close
20	1600g	3.0	300	7	1000	-	-	0	Blown, wire screen on top
21	1600g	3.0	300	0.5	1100	-	-	2.5	Intact, no screen, close at 7 min
22	1600g	3.0	300	10	1000	-	-	2	Blow at 300 psi, wire screen on top, close at 8 min
Run 4 - 0.5 x 50 x 50 in. boards									
23	52 lbs	3.0	300	7	1100	0.53	1.02	1	Intact, did not close
24	52 lbs	3.0	300	8	1200	0.58	0.95	1	Blown, close at 7 min
Run 6 - 0.5 x 12 x 15 in. boards									
40	1800g	7.8	325	8	1100	-	-	0	Blown, close & take out, did not reach stops
41	1800g	7.8	325	8	1100	-	-		Blown, bump at 5 min, did not close

(continued)

TABLE 1-33 (Continued) BOARD-MAKING CONDITIONS FOR DOUGLAS FIR FURNISH

Binder Number	Weight Formed	MC (%)	Temp (°F)	Time (min)	PSI	Thick- ness	Density	Decom- pression Time	Comments
42	1800g	7.8	340	10	1100			1	Blown, bump at 5 min, blose at 9 min
43	1800g	7.8	340	10	1100			1	Blown, bump at 5 min, close 7 min
Run 8 - 0.25 x 50 x 50 in. boards									
48	25.5lbs	7.8	325	6.5	1100	0.28	0.98	1.5	Blown, bump at 4 min, close at 4.5 min
49	25.5lbs	7.8	325	6.5	1100	0.27	1.02	1.25	Blown, press break down, repressed 2 days later - bump at 5 min
50	25.5lbs	7.8	325	6.5	1100	0.25	1.08	1.25	Blow at 25 psi, bump at 5 min, close at 4 min
51	25.5lbs	7.8	310	6.5	1100	0.26	1.04	1.25	Blown, bump at 5 min, close at 4.25 min
52	25.5lbs	4.5	310	6	1100	0.28	1.01	1.25	Intact, no bump, did not close
53	25.5lbs	4.5	310	6	1100	0.30	0.93	1.25	Intact, no bump did not close
54	25.5lbs	4.5	310	6	1100	0.32	0.89	1.25	Intact, no bump, did not close
Run 9 - 0.5 x 15 x 15 in. boards									
55	51 lbs	4.4	335	9.5	1200	0.39	0.93	1.25	Blown, no bump, close at 8.5 min
56	51 lbs	4.4	335	10	1200	0.55	0.98	1.25	Blown, bump at 5 min, close at 8.5 min
57	51 lbs	4.4	335	10	1200	0.54	1.01	1.25	Blown, bump at 8.5 min, close at 8 min
58	51 lbs	4.4	335	9	1200	0.55	0.97	4.00	Blown, no bump, press to Back to stops and take out pressure for 30 sec.

(continued)

TABLE 1-33 (Continued) BOARD-MAKING CONDITIONS FOR DOUGLAS FIR FURNISH

Board Number	Weight Formed	MC (%)	Temp (^{o}F)	Time (min)	PSI	Thick-ness	Density	Decom-pression Time	Comments
59	51 lbs	4.4	335	9	1200	0.57	0.97	1.25	Intact, bump at 5.5 min, close at 9 min
60	51 lbs	4.4	335	9	1200	0.57	0.96	1.25	Intact, bump at 5.5 min, close at 9 min.
61	49 lbs	4.4	335	9	1200	0.54	0.98	1.25	Blown, bump at 5.5 min, close at 9 min
62	49 lbs	4.4	335	9	1200	0.59	0.89	1.25	Intact, bump at 5.5 min, close at 9 min
63	49 lbs	4.4	335	9	1200	0.58	0.91	1.25	Intact, bump at 5.5 min, close at 9 min
64	49 lbs	4.4	335	9	1200	0.58	0.91	1.25	Intact, bump at 5.5 min, close at 9 min
65	49 lbs	4.4	335	9	1200	0.59	0.91	1.25	Intact, bump at 5.5 min, close at 9 min
66	49 lbs	4.4	335	9	1200	0.61	0.87	1.25	Intact, bump at 5.5 min, close at 9 min

imes were used. Treatment 69-48-3 at 4.5% MS, 310°F, a six minute press time without a bump cycle and a 1.25 minute decompression cycle produced intact boards. However, the press did not completely close on any of these.

Run 9: Twelve 0.5 inch thick by 50 inch by 50 inch boards were made in the final run. The only variations between boards were the press time, bump cycle, and the amount of furnish used. When the following conditions were established a series of nine boards were made with only one blown panel resulting. These conditions were: Binder Treatment 69-48-3, 51 and 40 pounds of furnish to form the board, 4.4% moisture content, 335°F press temperature, nine minute press time, 1200 psi closing pressure, a bump cycle of 5.5 minutes and 1.25 decompression period. The cause of the blow is not known, but apparently the conditions were again in the borderline category.

Table 1-34 presents the results of the tests for modulus of rupture,modulus of elasticity, and internal bond according to the American Society for Testing and Materials Standard D-1037, "Standard Methods of Evaluating the Properties of Wood-Base Fiber and Particle Panel Materials'. The results show that the material can qualify structurally but will require additional full scale studies to develop product reliability. The economics show that this process is equivalent to that of commercial board. Since there exists neither a cost advantage nor a structural advantage, the product was not pursued through qualification.

RECOMMENDED PROCESSING PROCEDURES

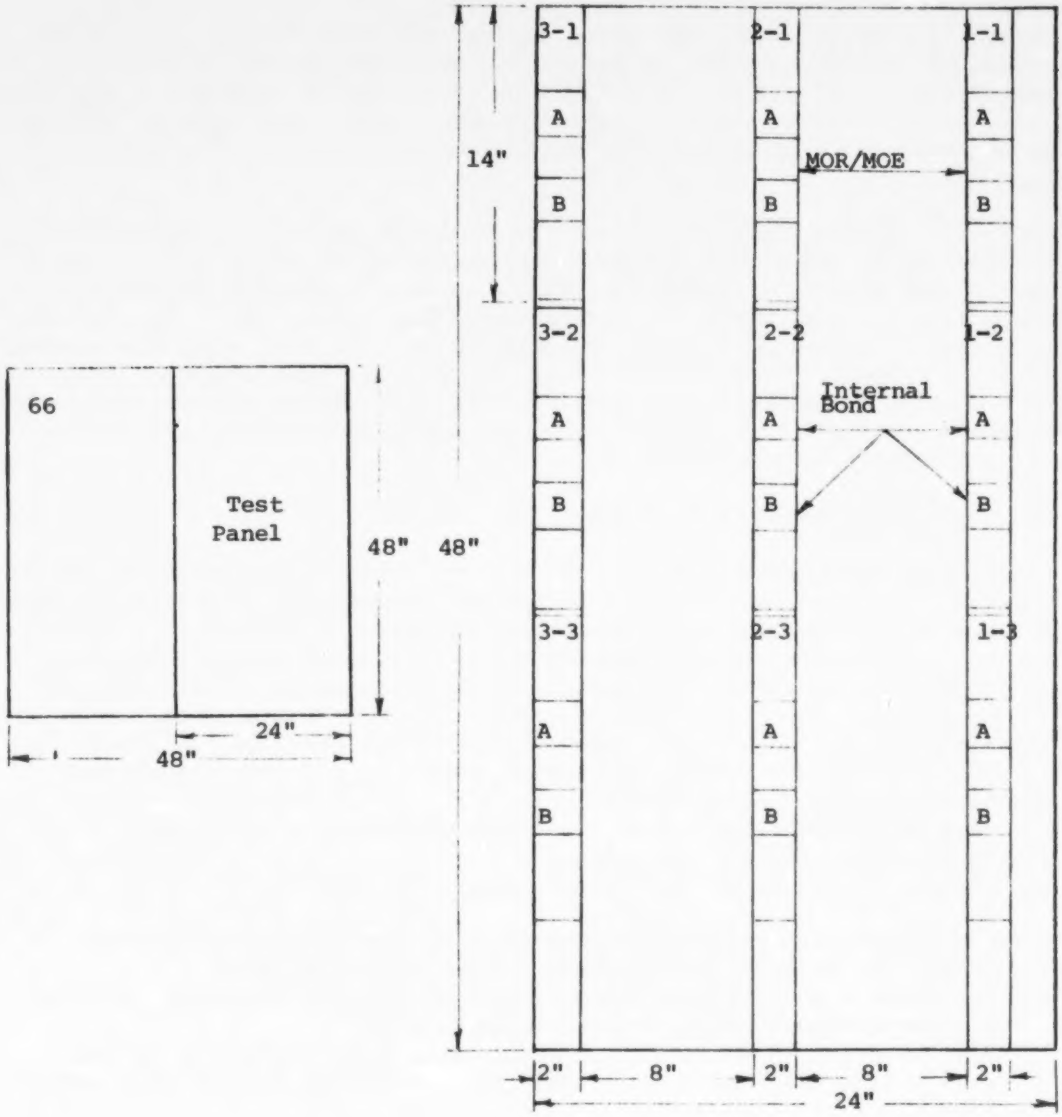
Peanut Hull Waste--Although further full scale development would be required to productize this material, the following is presented as a starting point.

a. Screen the material to eliminate all particles - 20 mesh.
b. Use a commercial blender and mix with the hulls a solution of water with 7% by weight by phosphoric acid (75% strength). Use 8 gallons of solution for 8.82 pounds of hulls. Mix for five minutes.
c. Place the mix in a dryer, remove and save the solution for reuse. Dry to 5.7% moisture content which will result in a 3.98% acid content.
d. Place in a pre-heated 355°F press.
e. Mold at 1200 psi for 3.5 to 4 minutes depending on thickness.
f. Close press within 2 minutes.
g. Use a 1.25 minute decompression time.

Wood Waste--Douglas Fir can be produced with the following procedure.

a. Screen the material to eliminate all particles -20 mesh.
b. Spray the wood particles with a solution of water containing 2.5% to 2.7% p-toluene sulfonic acid technical grade.
c. Place the mix in a dryer, remove and save the solution for re-use. Dry to 4.4% moisture content which will result in a 1.05% acid absorption.
d. Place in a preheated 335°F press.
e. Mold at 1200 psi for 9 minutes.
f. Use a pressure relief cycle, "bump", at 5.5 minutes.
g. Use full 9 minutes to close press.
h. Use a 1.25 minute decompression time.

TABLE 1-34 CUT-UP DIAGRAM AND PHYSICAL TEST RESULTS FOR BOARD 66 (DOUGLAS FIR FURNISH)


66
Test Panel
48"
24"
48"
48"
14"
3-1
2-1
1-1
A
B
MOR/MOE
3-2
2-2
1-2
Internal Bond
3-3
2-3
1-3
2"
8"
2"
8"
2"
24"

(continued)

TABLE 1-34 (Continued) CUT-UP DIAGRAM AND PHYSICAL TEST RESULTS FOR BOARD 66 (DOUGLAS FIR FURNISH)

MOR/MOE

Spec No.	SG	MOR	MOE (psi x 10^{-6})
1-1	0.84	1080	0.257
1-2	0.84	880	0.222
1-3	0.83	990	0.245
2-1	0.95	1830	0.455
2-2	1.00	2430	0.607
2-3	0.99	1970	0.564
3-1	0.96	1900	0.532
3-2	1.00	2130	0.582
3-3	1.00	2270	0.590

Internal Bond

Spec No.	SG	PSI
1-1A	0.82	28
1-1B	0.87	42
1-2A	0.84	32
1-2B	0.83	32
1-3A	0.82	33
1-3B	0.82	36
2-1A	0.97	84
2-1B	0.97	88
2-2A	1.02	99
2-2B	1.06	107
2-3A	0.98	86
2-3B	1.00	87
3-1A	0.96	90
3-1B	0.98	96
3-2A	1.02	95
3-2B	0.99	94
3-3A	1.00	106
3-3B	1.02	105

ECONOMICS

General--There are common factors to be used in both peanut hull and wood waste particle board economic analysis. These factors will be discussed first and then applied. This analysis is based on the references listed in Appendix A.

Capital Investment--The cost of a particleboard plant in 1975 dollars is approximately $3.2 million plus $135,000 per million square feet of annual capacity. This cost is estimated to be accurate within 10% of the estimate two thirds of the time.

Primitive plants of less than 100 million square foot capacity cost considerably less than the estimate given above, probably from $1 million for a 3 million square foot plant to $3 to $4 million for a 10 million square foot plant. The cost can vary a great deal depending on sophistication, precise process, and whether new or used equipment is purchased.

The waste process will require five to eight times as much drying capacity as conventional plants, an amount proportional to the increase in water content of the wood to be dried. It will also require centrifuge to reduce the water content.

The corrosive nature of the waste process may also require extensive use of stainless steel or fiberglass in storage tanks, dryers, presses, blenders and materials handling equipment. This requirement may cause a dramatic increase in the capital cost of a plant.

Labor--The number of workers required per shift in a particleboard plant can be calculated by starting with a base number of 21 and adding one worker per 8,000,000 square feet of annual capacity. Small plants are much more labor intensive than large ones.

Labor costs vary slightly with square feet and tonnage of board produced. This report will assume constant labor costs per 1000 square feet of board produced of $23.22.

Power--Power is directly related to tonnage of board produced and averages 250 KWH per 1000 sq. ft. of 3/4 inch 45# particleboard. Power is used primarily in refining (flaking, chipping, blending, and drying) and in pressing. Power cost assumed is $0.011 per KWH.

Heat--Heat is directly related to tonnage produced and averages 1,650,000 Btu (1,500 cu. ft. of natural gas) per 1000 sq. ft. of 3/4 inch, 45# conventional particleboard. Heat is required for drying the incoming wood and for heating the press. Btu required to raise temperature of water in wood to 212 degrees in dryer:

3000 lb wood x .15 water x 153 Btu per lb. = 68,850 Btu
Btu required to vaporize water in wood in dryer:
3000 lb wood x .14 water vaporized x 970 Btu per lb. = 407,400 Btu
Btu required to raise temperature of wood to 212 degrees in dryer:
3000 lb wood x .5 specific heat x 153 Btu per lb. = 229,500 Btu
Btu required to raise temperature of wood to 350 degrees in press:
3000 lb wood x .5 specific heat x 250 Btu per lb. = 375,000 Btu
Btu required to raise temperature of resin to 350 degrees in press:
3000 lb wood x .06 resin x 250 Btu per lb. - 45,000 Btu
Btu required to raise temperature of water in wood to 350 degrees in press:
3000 lb wood x .07 water x 250 Btu per lb. = 52,500 Btu
Btu required to vaporize water in wood in press:
3000 lb wood x .05 water vaporized x 970 Btu per lb. = 145,500 Btu

Total Btu calculated=		1,323,750
Total Btu required per industry data=		1,650,000
Process heat efficiency=		80%
Btu consumed in Drying	770,000	(47%)
Btu consumed in Pressing	880,000	(53%)
	1,650,000	

In the waste particle board process, the incoming wood at between 50 and 150 percent moisture is dried to 5 percent. It is then pressed at 350 degrees Farenheit where the moisture content is reduced to 2 percent.

The following is the composition of 1000 square feet of 45 pound per cubic foot density, 3/4 inch thick particleboard made by the waste process:

Material	Raw Material Reqd, lbs	Part by Weight	Finished Board, lbs
Wood	3,000	100	2,605
Binder	180	6	156
Water	1500 - 4500	2	52
	4680 - 7680	108	2,813

Btu required to raise temperature of water to 212 degrees in dryer:
3000 lb wood x 0.15 moisture x 153 Btu/lb = 68,850 Btu
3000 lb wood x 0.50 moisture x 153 Btu/lb = 229,500 Btu
3000 lb wood x 1.00 moisture x 153 Btu/lb = 459,000 Btu
3000 lb wood x 1.50 moisture x 153 Btu/lb = 688,500 Btu
Btu required to vaporize water in wood in dryer:
3000 lb wood x 0.10 moisture vaporized x 970 Btu/lb = 291,000 Btu
3000 lb wood x 0.45 moisture vaporized x 970 Btu/lb = 1,309,500 Btu
3000 lb wood x 0.95 moisture vaporized x 970 Btu/lb = 2,764,500 Btu
3000 lb wood x 1.45 moisture vaporized x 970 Btu/lb = 4,219,500 Btu
Btu required to raise temperature of wood to 212 degrees in dryer:
3000 lb wood x 0.50 specific heat x 153 Btu per lb = 229,500 Btu
Btu required to raise temperature of wood to 350 degrees in press:
3000 lb wood x 0.50 specific heat x 250 Btu per lb = 375,000 Btu
Btu required to raise temperature of binder to 350 degrees in press:

3000 lb wood x 0.06 binder x 250 Btu per lb = 45,000 Btu
Btu required to raise the temperature of water in wood to 550 degrees in press:
3000 lb wood x 0.05 x 250 Btu per lb = 37,500 Btu
Btu required to vaporize water in wood in press:
3000 lb wood x 0.03 specific heat x 970 Btu per lb = 87,300 Btu

Total Btu Required in Waste Process

Moisture	Total Btu Calculated	Btu Req'd at 80% Efficiency	Btu Used in Drying	Btu Used in Pressing
15%	1,134,150	1,420,000	740,000 (52%)	680,000 (48%)
50%	2,313,300	2,890,000	2,210,000 (75%)	680,000 (25%)
100%	3,997,800	5,000,000	4,320,000 (86%)	680,000 (14%)
150%	5,682,300	7,100,000	6,420,000 (90%)	680,000 (10%)

For purposes of this report, gas will be presumed to cost $0.50/100 cu. ft. and the conventional process to utilize wood at 15 percent moisture (planer shavings) while the waste process used wood at 100% moisture (planer shavings soaked in acid bath and spun dry) or estimated 50% moisture (spray technique).

The calculation of heat required does not include the heat needed to remove humidity from the air coming into the dryers. Industry sources estimate that a conventional particleboard plant will use twice as much heat on a humid day as on a normal day. Since the conventional process uses about 47% of its Btu requirements to dry the incoming wood while a plant using the waste process and wood at 100% moisture used 86% of its Btu requirement to dry the wood, humid days would increase the Btu requirements of a waste plant to 285% of normal compared to 200% for a conventional plant.

Also not included in the Btu calculations are extra heat requirements to cause the water to be released from the acid in the waste process, or the effect of exotherm during pressing. These factors are believed to have a small impact on total Btu requirements.

Overhead--The following are overhead costs for a 60 million square foot plant per year:

Salaries:		
Plant Manager	33,000	
Plant Supervisor	24,000	
Technical Director	20,000	
Bookkeeper	16,000	
Clerk/Typist (2)	24,000	
Shipping Clerk	16,000	
Insurance	50,000	
Property Taxes	90,000	
Office Expenses	80,000	
		220,000
		353,000
Overhead per 1,000 square feet		$5.88

Peanut Hull Waste--The minimum density of acceptable particle board from peanut hull waste is 55 pounds per cubic foot. This will be the density used in the cost analysis. In this study the soak and dry process was used to treat the peanut shells. It was possible to recover all but 5.8% of the acid in one case and 6.8% in the other (Table 1-3). Further drying at Washington State University reduced the acid absorption content to 4%. It is reasonable to assume that this extra 2% could be recovered also with a controlled process. Although not tried in this program, it is also reasonable to assume that the spray process would work with peanut hulls as well as with wood waste. Therefore, an acid absorption value of 4% is used in the following cost analysis. In addition the spray process reduces the moisture content to be removed from the wood resulting in lower fuel costs.

Assumptions:

3/4 inch board
15% scrap reprocessed
Conventional Board: 55# density - 8% resin
Urea Resin Cost - 10.5¢/lb
Phenolic Resin Cost - 27¢/lb.
Waste Process Board: Wood - 0.4¢/lb
55# density - 4% phosphoric acid
Phosphoric Acid Cost - 18¢/lb.
Peanut Hulls - .75¢/lb.

Material Used (Pounds per 1000 square feet)

	Conventional			Waste Process
	55# Urea	55# Phenolic		
Wood	3667	3667	Peanut Hulls	3667
Binder	293	293	Acid	147
Wax	37	37		
	3997	3997		3814

Material Cost (Dollars per 1000 square feet)

	Conventional			Waste Process
	55# Urea	55# Phenolic		55#
Wood	15.03	15.03	Peanut Hulls	27.50
Binder	30.77	79.11	Acid	26.46
Wax	1.85	1.85		
	47.65	95.99		53.96

If no additional resin or wax is needed to reprocess waste scrap and normal amounts are required to reprocess conventional scrap, the reprocessing costs are:

Material Cost of Scrap (Dollars per 1000 square feet)

	Conventional			Waste Process
	55# Urea	55# Phenolic		55#
Wood			Peanut Hulls	-
Binder	30.77	79.11	Acid	-
Wax	1.85	1.85		
	32.62	80.46		0

If 15% of the board produced is scrap, the materials cost of a finished board is:

Material Cost of Finished Board (Dollars per 1000 square feet)

	Conventional		Waste Process
	55# Urea	55# Phenolic	55#
Primary Run 85%	40.50	81.59	45.86
Scrap Re-Run 15%	4.89	12.14	-
	45.39	93.73	45.86

The total manufacturing costs in a 60,000,000 square foot particleboard plant are:

Item	Conventional 55# Urea	Conventional 55# Phenolic	Waste Process 55# Soak Test	Waste Process 55# Spray Test
Variable Costs				
Materials	45.39	93.73	45.86	45.86
Power	3.36	3.36	3.36	3.36
Fuel	.92	.92	2.77	1.60
Labor	23.22	23.22	23.22	23.22
Maint & Supplies	2.44	2.44	2.44	2.44
	75.33	123.67	77.65	76.48
Fixed Costs				
Overhead	5.88	5.88	5.88	5.88
Depreciation	18.83	18.83	18.83	18.83
	24.71	24.71	24.71	24.71
Total Costs	100.04	148.38	102.36	101.19

From this analysis it is apparent that no economic advantage over conventional wood particle board exists with peanut hulls. However, in the event that large supplies of the waste exists, it could be an advantageous method for waste utilization.

Wood Waste--The minimum density of acceptable particle board from wood waste is 55 pounds per cubic foot also. The spray technique for treating the wood waste was demonstrated to be acceptable. The p-toluene sulfonic acid is used at an absorption content of 1.05% of the wood weight. All other acids can be removed.

Assumptions:

3/4 inch board
15% scrap reprocessed
Conventional Board: Wood - 0.4¢/lb
55# density - 8% resin
Urea Resin Cost - 10.5¢/lb
Pehnolic Resin Cost - 27¢/lb
Waste Process Board: 55# density - 1.05% p-Toluene Sulfonic Acid
p-Toluene Sulfonic Acid Cost - 23¢/lb

Material Used (Pounds per 1000 square feet)

	Conventional		Waste Process	
	55# Urea	55# Phenolic		55#
Wood	3667	3667	Wood Waste	3667
Binder	293	293	Acid	39
Wax	37	37		
	3997	3997		3706

Material Cost (Dollars per 1000 square feet)

	Conventional		Waste Process	
	55# Urea	55# Phenolic		55#
Wood	15.03	15.03	Wood Waste	15.03
Binder	30.77	79.11	Acid	8.97
Wax	1.85	1.85		
	47.65	95.99		24.00

If no additional resin or wax is needed to reprocess waste scrap and normal amounts are required to reprocess conventional scrape, the reprocessing costs are:

Material Cost of Scrap (Dollars per 1000 square feet)

	Conventional		Waste Process	
	55# Urea	55# Phenolic		55#
Wood	-	-	Wood Waste	-
Binder	30.77	79.11	Acid	-
Wax	1.85	1.85		
	32.62	80.46		0

If 15% of the board produced is scrap, the materials cost of a finished board is:

Material Cost of Finished Board (Dollars per 1000 square feet)

	Conventional		Waste Process
	55# Urea	55# Phenolic	55#
Primary Run 85%	40.50	81.59	20.40
Scrap Re-Run 15%	4.89	12.14	-
	45.39	93.73	20.40

The total manufacturing costs in a 60,000,000 square foot particleboard plant are:

Total Cost (Dollars per 1000 square feet)

Item	Conventional		Wood Process
	55# Urea	55# Phenolic	55#
Variable Costs			
Materials	45.39	93.73	20.40
Power	3.36	3.36	3.36
Fuel	.92	.92	1.60
Labor	23.22	23.22	41.80 (1)
Maint & Supplies	2.44	2.44	2.44
	75.33	123.67	69.60
Fixed Costs			
Overhead	5.88	5.88	5.88
Depreciation	18.83	18.83	18.83
	24.71	24.71	24.71
Total Cost	100.04	148.38	94.31

(1) The time to process the panel is 9 minutes rather than 5 minutes used conventionally. This labor cost could be reduced by using a press with more openings but this would increase capital cost and depreciation cost.

This product has limited economic advantages and is limited to a minimum density board of 55 pounds per cubic foot in a market where the predominate sales are with 45 pounds per cubic foot. The effort on this program was not sufficient to develop full processing parameters. Although the limitations are known, not all of the potentials have yet been established.

PROCESSING WITH DOUGLAS FIR FINES

Past work with peanut hulls and wood particles indicated that the fines from either generated more resin than larger particles; this in turn caused processing problems because of excessive shrinkage and/or blowing or blistering from excessive steam evolution. It was proposed to study the fines as a source of resin but in the presence of other materials to act as reinforcement and to permit escape of steam.

First efforts were to examine the fines alone to determine the problem areas. Douglas Fir, hammermilled material, was screened and all the -20 mesh material used. Three formulations were made, each soaking 1000 g of fines in a *p*-toluene sulfonic acid solution made from 150 g *p*-toluene sulfonic acid and 2500 g of water (I), 1125 g *p*-toluene sulfonic acid in 2500 g of water (II) and 75 g *p*-toluene sulfonic acid and 2500 g of water. After soaking for 30 minutes the material was spun in a centrifuge to remove most of the acid solution. The wet material was dried until a moisture content of about 7% was achieved. The data are shown in Table 1-38.

The data in Table 1-38 indicate some outstanding strength retention after 24 hour water soak with minimal water pickup. Again this is achieved at densities higher than commercial high density boards and at a cost for acid which makes cost greater than present commercial material. However this may be mitigated under certain conditions and should not be excluded from further considerations where price is not the critical factor.

Again the data showed that the amount of acid picked up by the wood is crucial to determining strength dry and wet. With an acid pickup of 2.8% the final product soaked up so much water as to render it unhandleable or testable. An acid pickup of 4.2% gave excellent results while the 5.7% acid pickup gave outstanding properties.

The very poor results with 1/8" chopped glass added was due to several factors with poor wet out of glass and wrong amount of glass being the most critical factors visible.

Due to time remaining on the program and the need of funds for more promising products, further work with the particle board products was halted.

RECOMMENDATIONS AND CONCLUSIONS

Peanut Hull Waste--The resulting product is limited to a minimum weight of 55 pounds per cubic foot and without the benefit of some fibrous reinforcement will not be able to achieve a modulus of rupture of 2400 psi. However, values of 1400 psi to 2100 psi (see Tables 1-4 and 1-32) are respectable. The economics of the product are marginal based on the present price of peanut hulls. This price would change dramatically if there were large surplus quantities of hulls which required disposal. In the United States peanut hulls have many uses and are a marketable waste. However, in many of the developing nations peanuts are major crops with oil as the primary product. It is these nations which could make use of this product.

Assuming that interest exists in the product, there exists at least one year of process development on full-scale equipment. This program demonstrated a process that can make 50 inch by 50 inch panels although not consistently. It is believed that the acid content and moisture content have been established. Further studies are required on
a) Particle size and distribution
b) Pressures
c) Pressure relief and decompression cycles, and
d) Fiberous reinforcements

It is recommended that the Environmental Protection Agency make this process available to the Department of State for exploitation abroad.

Wood Waste--This product is limited to a minimum weight of 55 pounds per cubic foot also. Modulus of rupture values in excess of 2400 psi were

TABLE 1-35 CHIP BOARD PRODUCT USING DOUGLAS FIR FINES WITH P-TOLUENE SULFONIC ACID

Batch	% Conc'n Acid Solution	% Acid Pickup by Wood	Moisture Content %	Time Mins	Temp ^{o}F	Pressure psi	Density	Flexure MOR psi
I	6.0	5.7	7.3	5	300	750	1.05	849
I	6.0	5.7	7.3	10	300	750	1.30	3486
I	6.0	5.7	7.3	5+5	300	500	1.18	2874
II	4.5	4.2	7.8	5+5	300	500	1.16	3296
II	4.5	4.2	7.8	15	300	500	1.26	3176
II	4.5	4.2	7.8	5	325	500	1.18	3171
III	3.0	2.8	7.6	5	300	500	1.08	2044
IIIA	3.0	2.8	7.6	5	300	500	1.24	3204
IV	6.0	5.7	7.6	5	300	750	1.18	2402

achieved (Tables 1-12 and 1-34) although not consistently. The product has some economic advantage. This advantage could be increased by judicious process development work. This program demonstrated a process that can make 50 inch by 50 inch board somewhat consistently (see Run 9 - Table 1-33). However, additional process development is required on full scale equipment to define

a) Particle size and distribution
b) Pressures, and
c) Pressure relief and decompression cycles.

It is, therefore, mandatory that an existing particle board manufacturer become interested in the process in order to further this development.

SECTION 3

WASTE PRODUCTS USING AN INORGANIC MATRIX

INTRODUCTION

The Phase II study developed two classes on inorganic materials. One was an inorganic matrix foam using rice hulls. The other was a dense inorganic matrix reinforced with wood waste and/or rice hulls as a lumber substitute. The rice hull foam could be produced from a variety of formulations. Within the denser range products suitable for structural walls, floors, ceilings, and combination floor-ceilings could be produced with a possible two or three hour fire rating. On the opposite end of the density scale, a rice hull foam could be produced which could be used as a core for a fire door.

The purpose of Phase III was to scale up the Phase II data and to produce full scale products, test and qualify them. The products evaluated are discussed below.

WALL SYSTEM

Material Selection-- There were a variety of rice hull foam formulations evaluated but the one selected for qualification is presented in Table 2-1.

The MSC additive improves the water resistance of the material. Once the material has cured, the moisture content stabilizes at 10%. Then the weight and cost distribution of the foam is as shown in Table 2-2.

TABLE 2-1 RICE HULL FOAM FORMULATION

Constituent	Amount, lbs
Water	100
Rice Hulls	57
Untreated Glass Fibers	3.4
MSC Additive	5
Plaster	343
Bussan 30	0.6

TABLE 2-2 CURED WEIGHT AND COST DISTRIBUTION

Constituent	Cured Weight lb	Cost/lb	Total Cost
Water	46	-	-
Rice Hulls	57	$0.62 *	$3.534
Untreated Glass Fiber	3.4	.40	1.360
MSC Additive	5	.432 *	2.160
Plaster	343	.0252	8.644
Bussan 30	0.6	2.75	1.6500
Total	455	.038	17.348

* Price delivered to factory.

This formulation was selected for its properties and resistance to water. The effects of water on the strength retention of rice hull foam was studied by constructing a panel and cutting it into 144 compression blocks, 1" x 1" x 2" in size. Thirty-six of the blocks were uncoated. The remaining blocks had their exterior surfaces coated with one of the following three materials.

a. Swimming Pool Paint produced by Zynolite Products Corporation
b. Lytron 621 produced by Monsanto
c. W-102 produced by Wetco Chemicals

Nine each of the four classes of specimens were immediately tested as controls. Eighteen of each class were placed into separate jars of water. These specimens were soaked in the same water throughout the test period. The remaining nine specimens of each class were placed in separate jars of water in which the water was changed daily. The purposes of the tests were to determine the following:

a. The effects of one day, one week, and one month of complete submersion in water on strength retention.
b. The effect of standing water versus transient water on strength retention.
c. The effects of surface coating on strength retention.
d. The ability of the material to regain its strength after drying out.

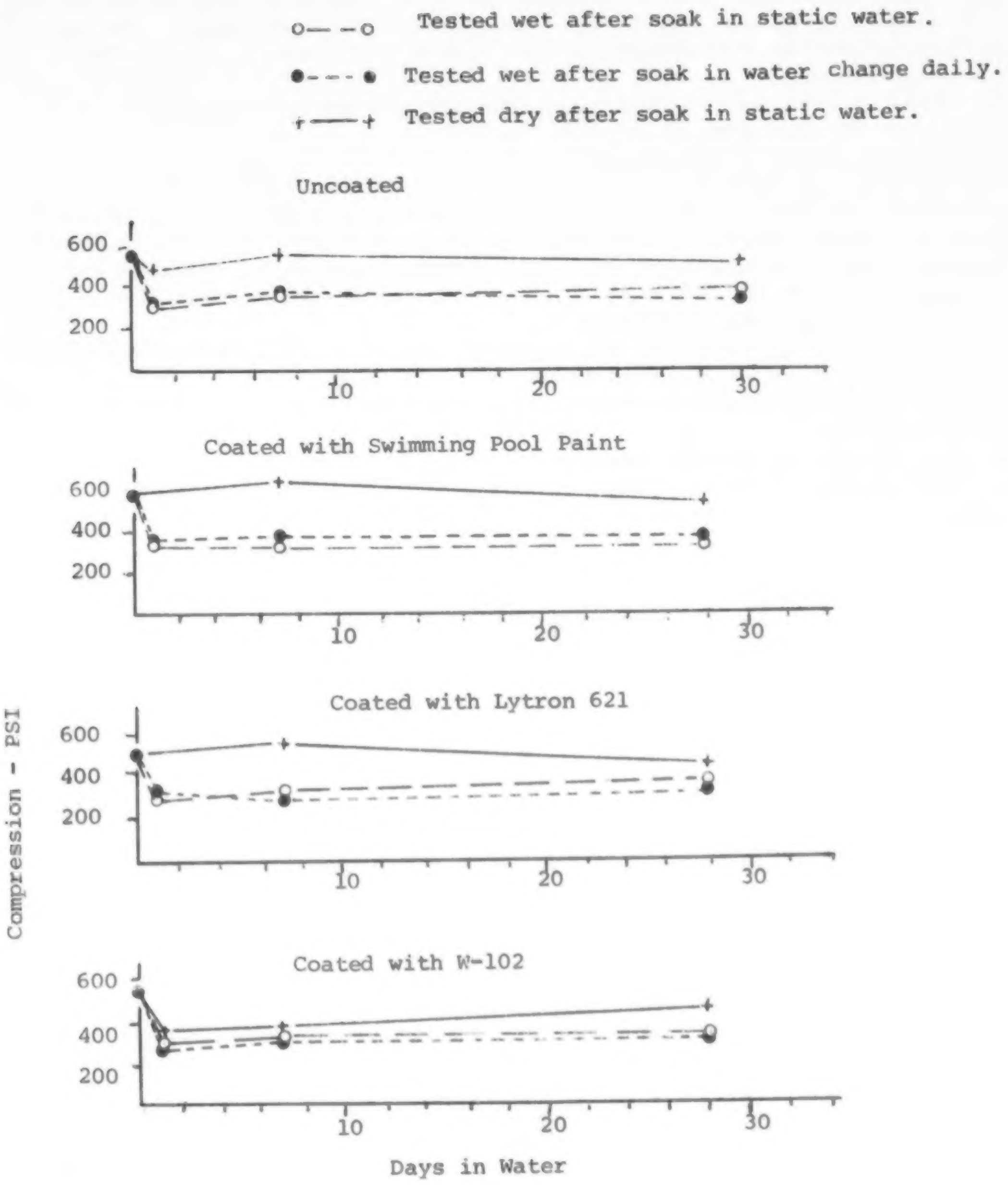
Samples of kiln dried Douglas Fir, a standard building material, were subjected to the same tests as a comparison.

The tabulated data for these tests are presented in Appendix B. Figure 2-1 presents a graphical summary of these results. A study of these curves will establish the following conclusions:

a. The uncoated sample performed as well or better than the coated ones.
b. The major reduction in strength when tested wet occurs the first day. After that, over a month's period of submersion, there is very little change. In all cases there appeared to be even a slight regain in wet strength.
c. W-102 coating appears to have an adverse effect.
d. Up to one week submersion there appears to be a 100% regain in strength on all but W-102 coated samples, when the material dries out. After one month submersion strength retention upon drying out appears to be between 82% and 97%.

Figure 2-2 compares the uncoated samples strength retention against the strength retention of Douglas Fir, a common building material. It is amazing that the wet strength results on a percentage basis are nearly identical. Unfortunately the effect of one day submersion on wood was not determined.

The average wet compression load after 30 days submersion is slightly over 300 psi. The area of a linear foot of wall as now designed is 15.5 square inches. Thus the wall wet after 30 days submersion will support up to 4650 pounds per linear foot. A typical maximum wall design load would range from 800 pounds to 1200 pounds per linear foot. Therefore, this wall would provide the required Factor of Safety of 3 with some additional margin.



Uncoated

Coated with Swimming Pool Paint

Coated with Lytron 621

Coated with W-102

Figure 2-1. Effects of water on strength retention.

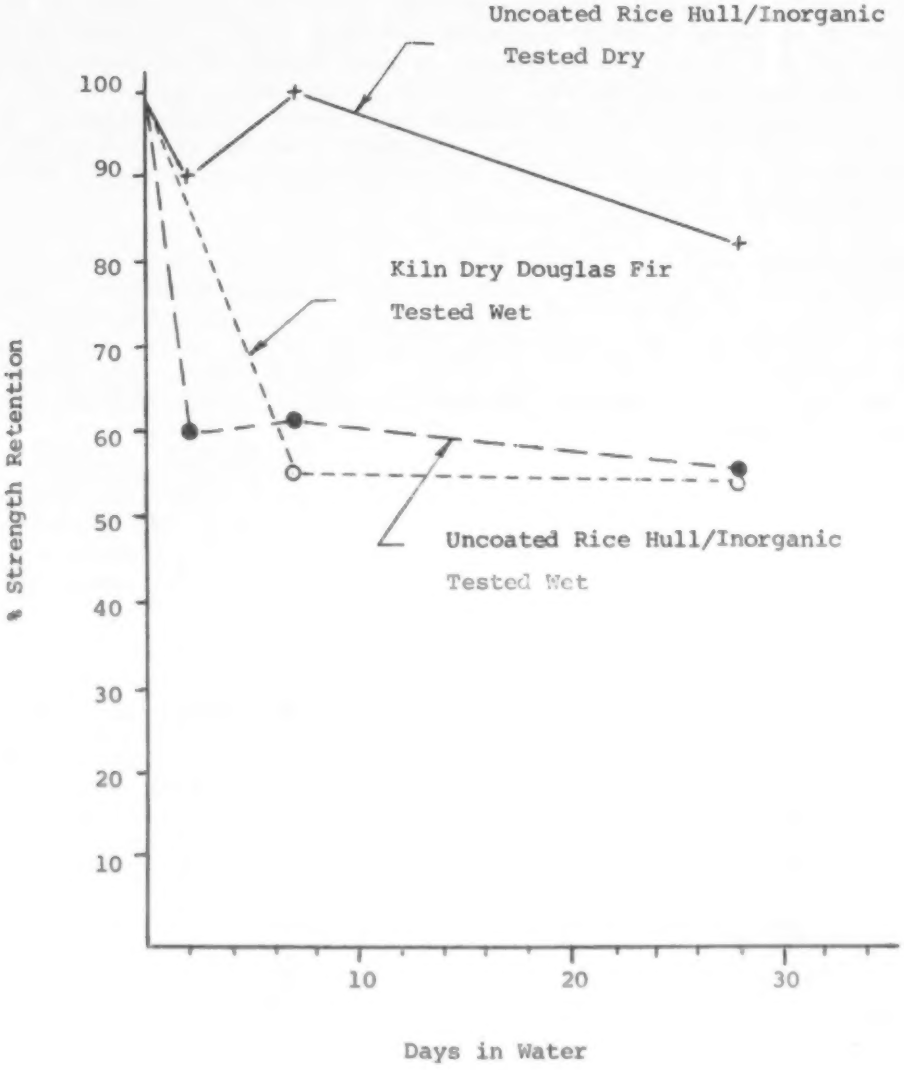


Figure 2-2. Percent strength comparison of rice hull/inorganic and wood.

The mechanical properties of the foam were evaluated by Testing Engineers of San Diego. The mean results are summarized in Table 2-3 and the detail data are presented in Appendix C.

The first sample population for compression testing was too small for a foam material and had to be retested with a larger population. The test scatter is a result of the size of the specimen which is small compared to the variation in porosity distribution from the rice hulls. The tensile value appears low and in all reality would be much higher if evaluated in a four foot wide specimen rather than one with a one inch cross section. However, 54 psi is adequate when the maximum wall tensile load probable for a house is 115 lbs per linear foot. The wall cross section of 15.5 square inches would result in a tensile stress of 7.4 psi providing a safety factor of 3 with considerable to spare.

Design Selection--The initial work in Phase II on full scale walls utilized a molded shape bonded at the center line with an inorganic adhesive. This is shown in Figures 2-3 and 2-4. These panels required considerable materials and expensive fiberglass. The panels always failed in the center borderline as could be expected since this is the point of maximum shear. Therefore, an attempt was made in this phase to produce a monolithic wall having a thickness of 3 1/2 inches.

TABLE 2-3 MECHANICAL PROPERTIES OF RICE HULL FOAM

Property	psi
Compression Strength	952
Tensile Strength	54
Modulus of Rupture	165
Shear Strength	1,361

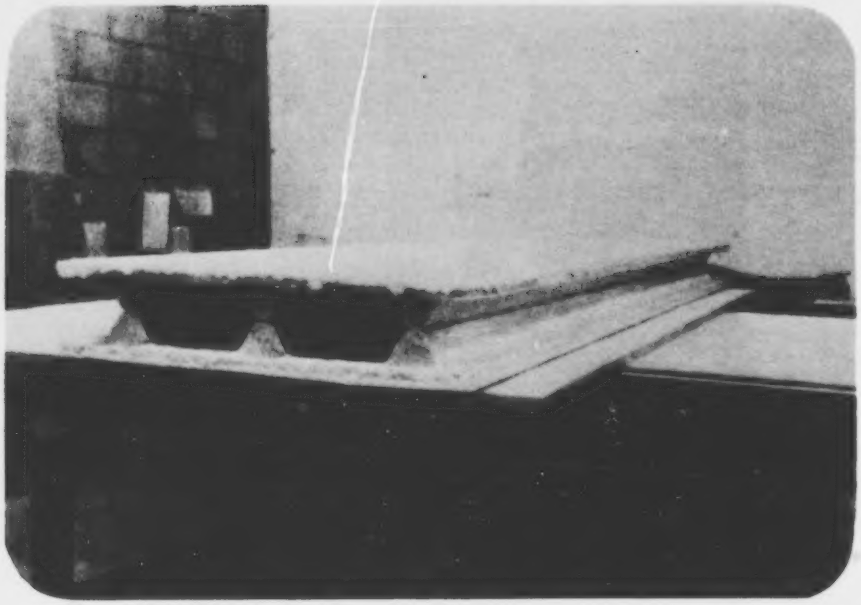


Figure 2-3. Cross section of Phase II wall.

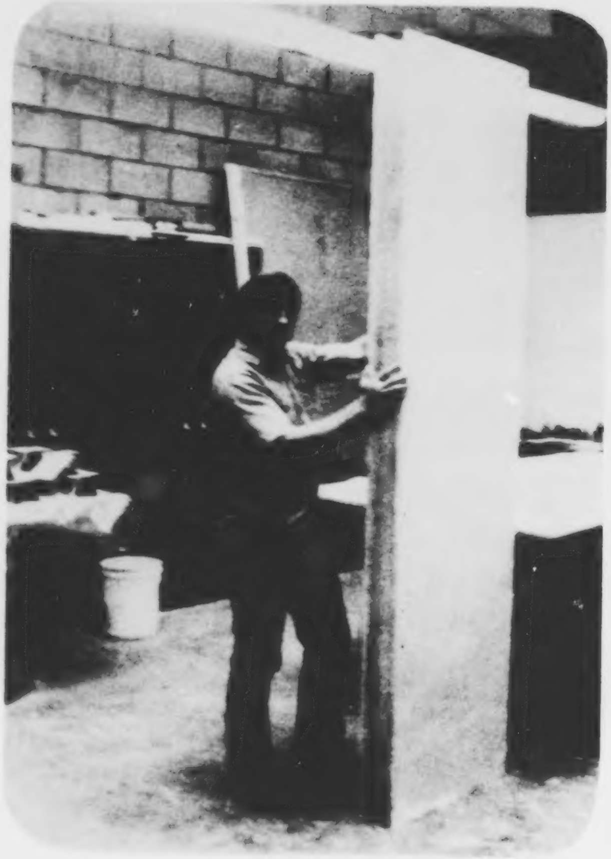


Figure 2-4. Full-scale Phase II wall.

The mold was made in such a way that inserts were used to form the ribs and void space and these were removed by slowly forcing out the inserts. Despite the generous use of wax, as a parting agent, it was not possible to remove the inserts without damage to the final structure. The design was then changed to produce elements as shown in Figure 2-5 and 2-6. The internal dimension of 3 1/2 inches was chosen for compatibility with conventional construction. These panels could be extruded or cast continously by machine. The length selected for this study was 8 feet. The elements for this study were cast easily on the tool shown in Figure 2-7. The elements were then bonded together to form the wall as shown in Figure 2-8.
Compression Strength of Wall-- The first compression test conducted to verify this design was on a two foot wide by four foot long specimen shown in Figure 2-9 and 2-10. This resulted in a failure load of 6000 pounds per linear foot. This was then followed by three full scale qualification tests on four foot wide by eight foot long panels. A diagram of the compression test set up is shown in Figure 2-11 and Figure 2-12 shows a panel ready for testing. A representative of Testing Engineers-San Diego witnessed the fabrication and bonding of all panel components.

The sample panels were tested at Material Systems Corporation's plant, Escondido, California. The compressive load was applied by means of a hydraulic system recently calibrated by Testing Engineers-San Diego. The test set-up was as described in ASTM E-72-74 (a) and illustrated in Figures 2-11 and 2-12.

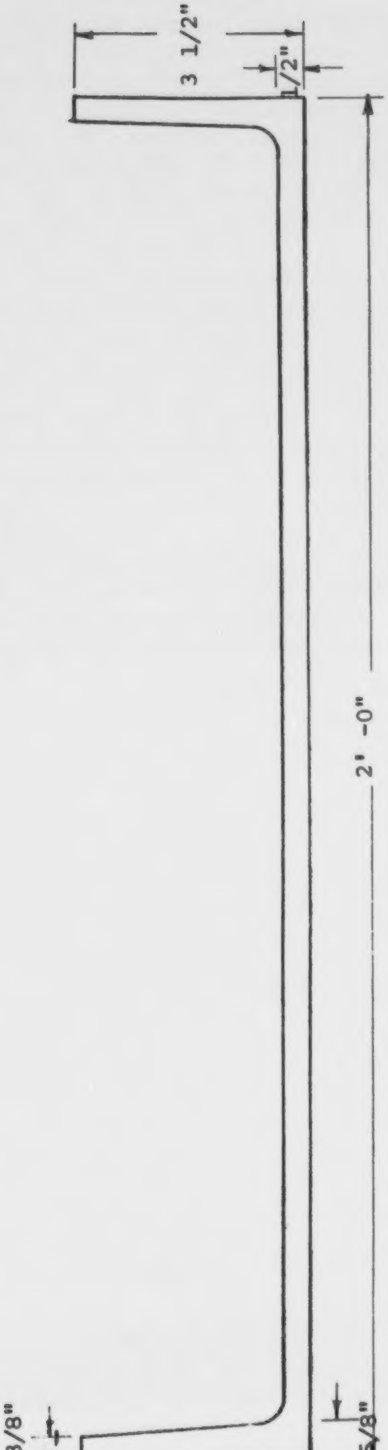

3 1/2"
1/2"
2' -0"
3/8"
5/8"

Figure 2-5. Cross section of wall material.

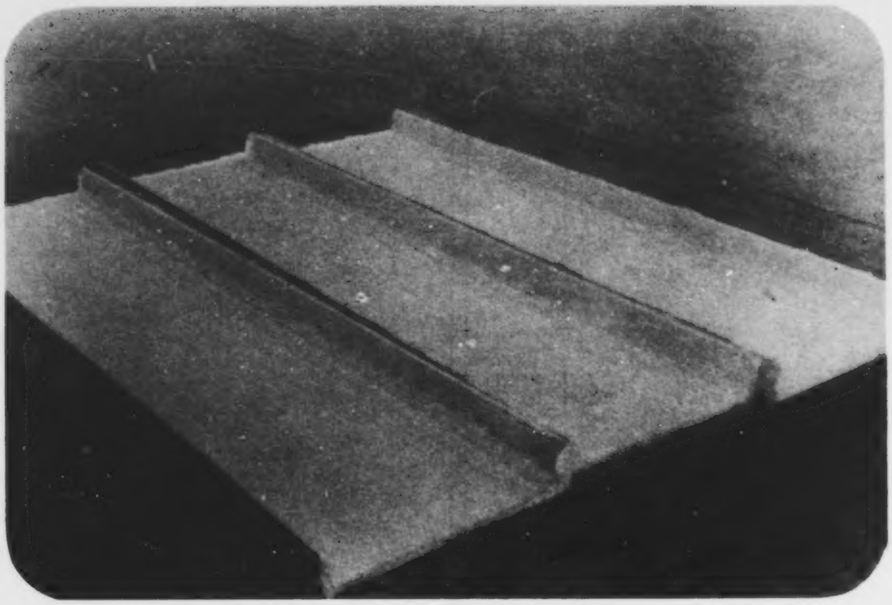


Figure 2-6. Rice hull foam wall elements.

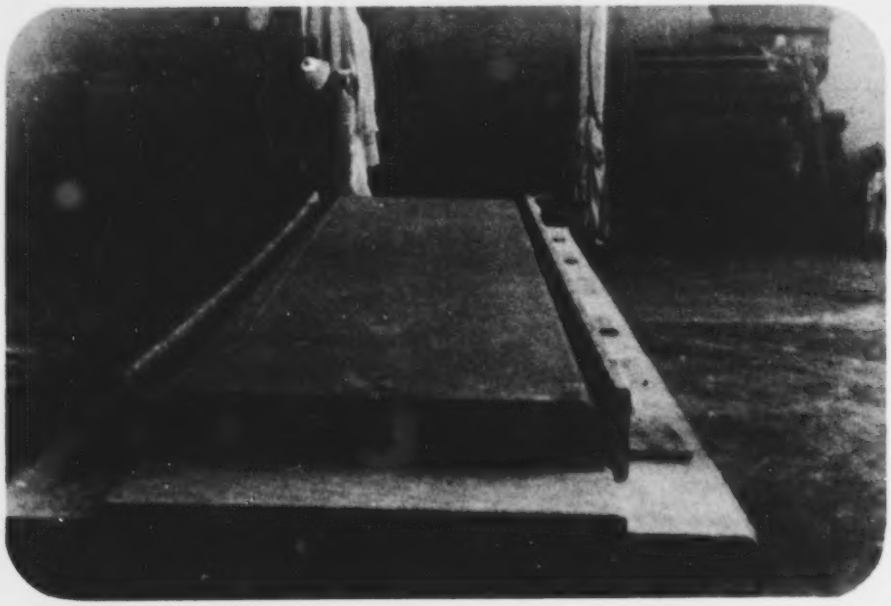


Figure 2-7. Tooling for scale-up studies.

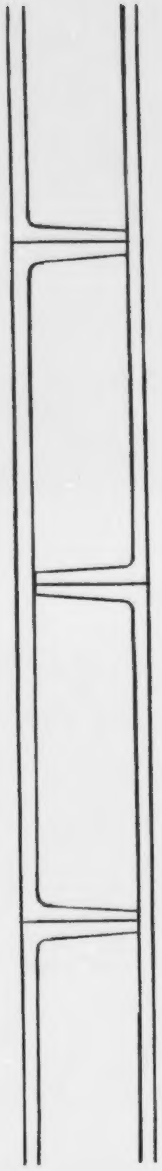


Figure 2-8. Assembly of wall material into a panel.

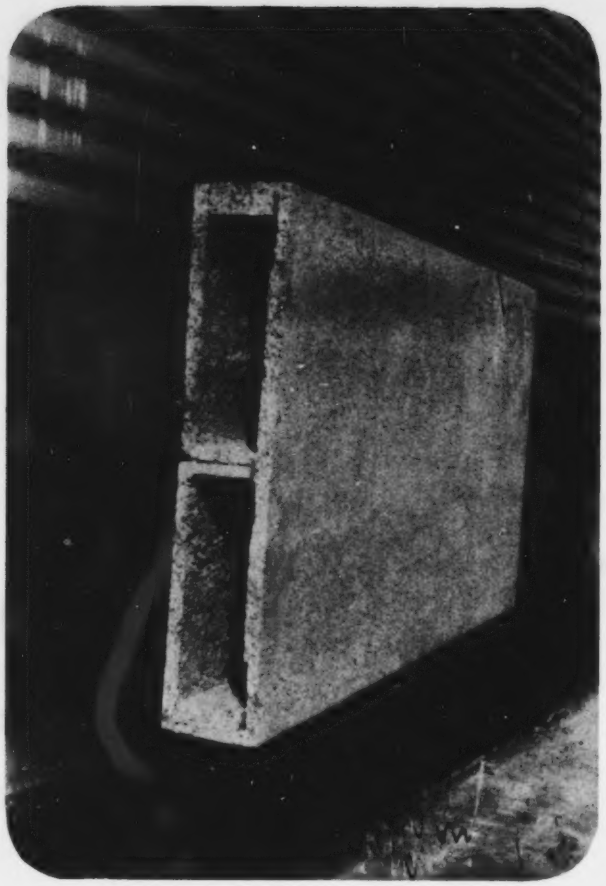


Figure 2-9. Cross section of specimen.

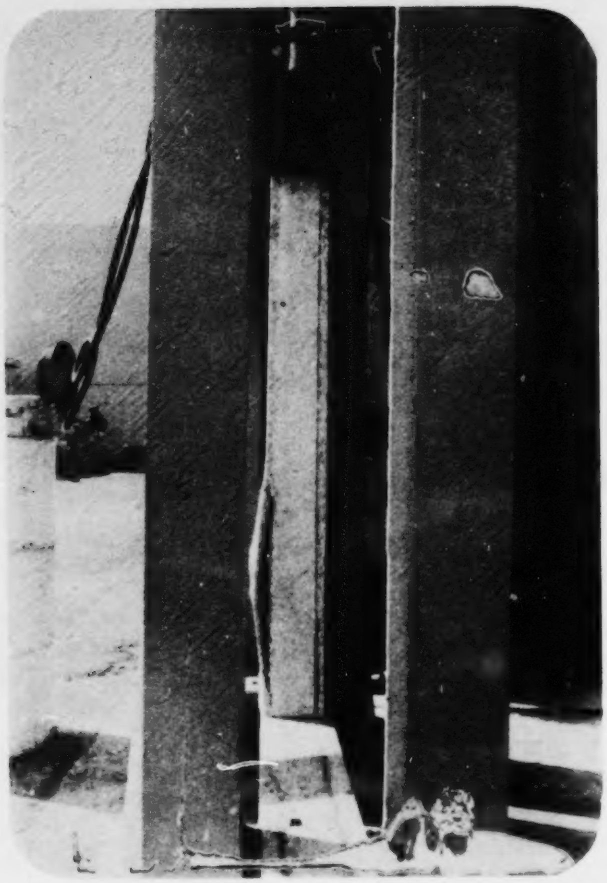


Figure 2-10. Compression failure.

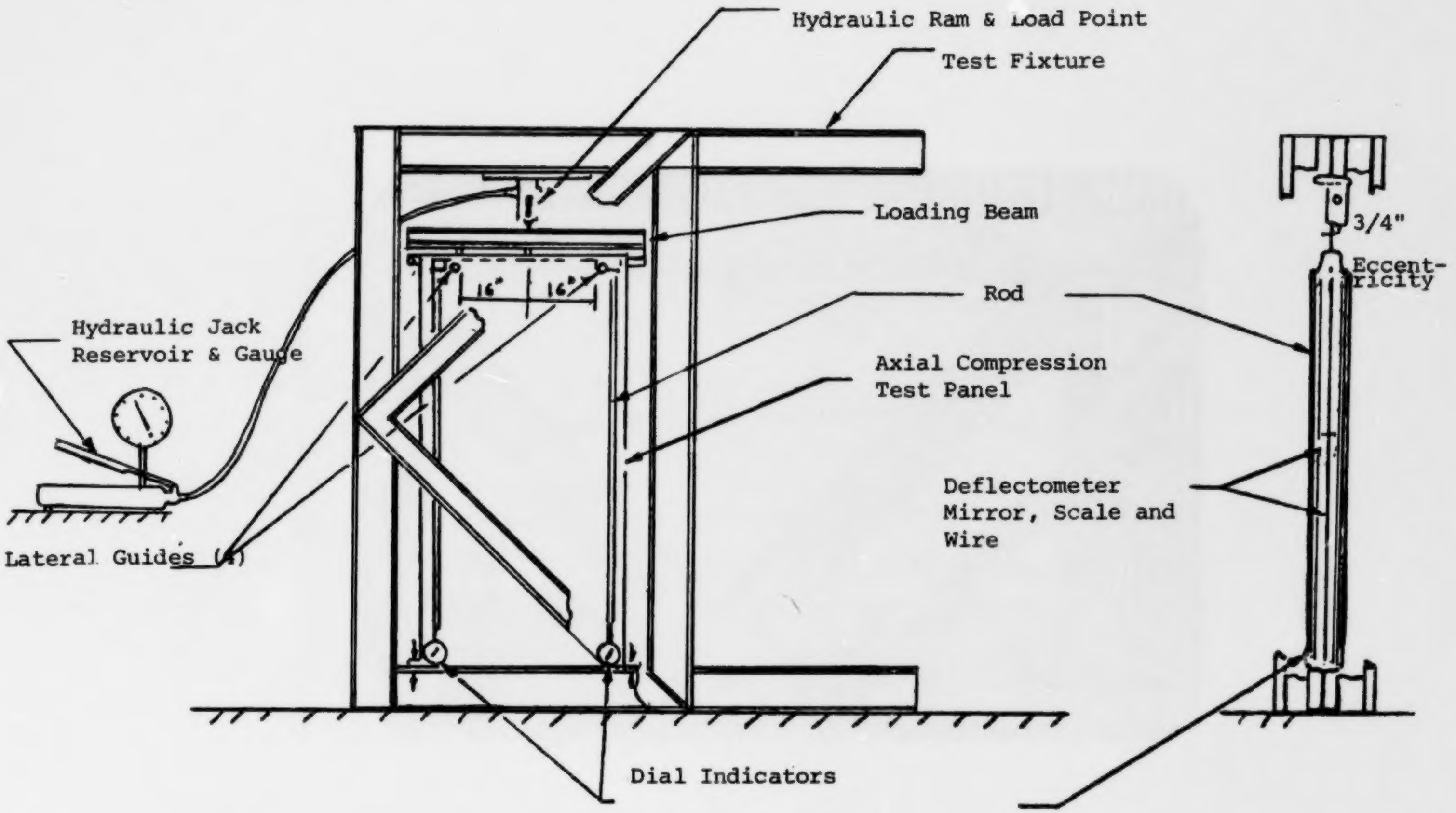

Hydraulic Ram & Load Point
Test Fixture
Loading Beam
Rod
Axial Compression Test Panel
Deflectometer Mirror, Scale and Wire
3/4"
Eccentricity
16"
16"
Hydraulic Jack Reservoir & Gauge
Lateral Guides (4)
Dial Indicators

Figure 2-11. Material Systems Corp. panel axial compression test set-up.

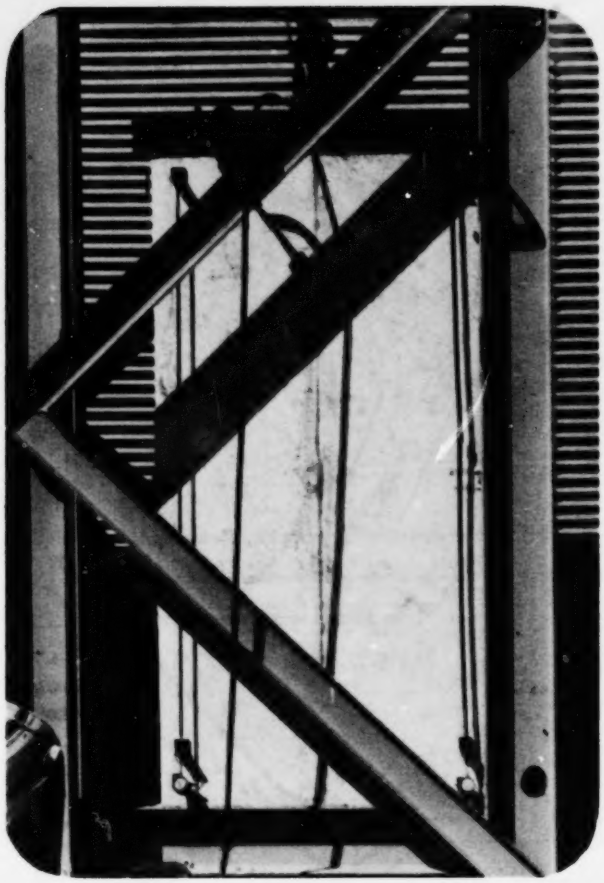


Figure 2-12. Full-scale compression test.

Lateral buckling of the panel was measured at mid-height by 0.01 inch taut wire deflectometers on each panel edge. Axial compression of the specimen under load was measured by means of 0.001 inch steel rod compressometers on each of the four corners of the panel. The panel was pre-loaded to approximately 400 pounds prior to setting deflection gauges. The loading was then applied in increments of approximately 600 pounds in test SD31-1226 and 900 pounds in test SD31-2043 until failure occured. After each loading increment the load was returned to zero and set measurements were made.

The details of these tests are presented in Appendix C. Figure 2-13 presents the relationship of load to deflection and permanent set. Test SD31-1226 was the first full scale panel produced and tested. Tests SD31-2043 were panels produced in a simulated production run and were selected at random. It is believed that these later panels represented a better quality product and this is the reason for a more stiffer product and one with less permanent set.

In either case, the wall is considerably stiffer than other qualified systems and exhibits less permanent set. The qualifiable design allowable is the ultimate divided by a factor of safety of 3 and the width of the panel.
Panel SD31-1226: 31,800/3 x 4 = 2,650 lb/ft
Panel #1 (SD31-2043): 30,000/3 x 4 = 2,500 lb/ft
Panel #2 (SD31-2043): 28,000/3 x 4 = 2,333 lb/ft

The test curve indicates that the panel was within its elastic limit. Therefore, the certified allowable will probably be 2,333 pounds per foot which is approximately twice that of a stud wall.
Racking Shear Strength of Walls--These tests are also required for structural wall qualifications. A 48 inch by 96 inch panel was fabricated per Figure 2-14 for a racking shear test. Because of the low tensile strength of the material it was decided to incorporate a 0.040 inch thick fiberglass strip at the lower bottom corner to assist in transfering tension at that point. The upper and lower sill plates are 2" x 4" lumber bonded with epoxy to the panel.

The panel was tested in the Material Systems Corporation's fixture shown in Figure 2-15. The results of this test are shown in Figure 2-16. The deflection under load shows that this panel is considerably stiffer than an ICBO approved panel now in production. Also the failure load is approximately four times higher than that of the approved panel. The allowable racking shear load is the lower of the load that creates 1/8 inch lateral deflection or the failure load divided by a factor of safety of 3. In this case both values are the same, 450 pounds per foot for a four foot wide panel. The failure of this panel was one of pure theoretical shear in which a shear crack formed diagonally across the panel. These test results were sufficiently high to encourage a repeat test without the strips.

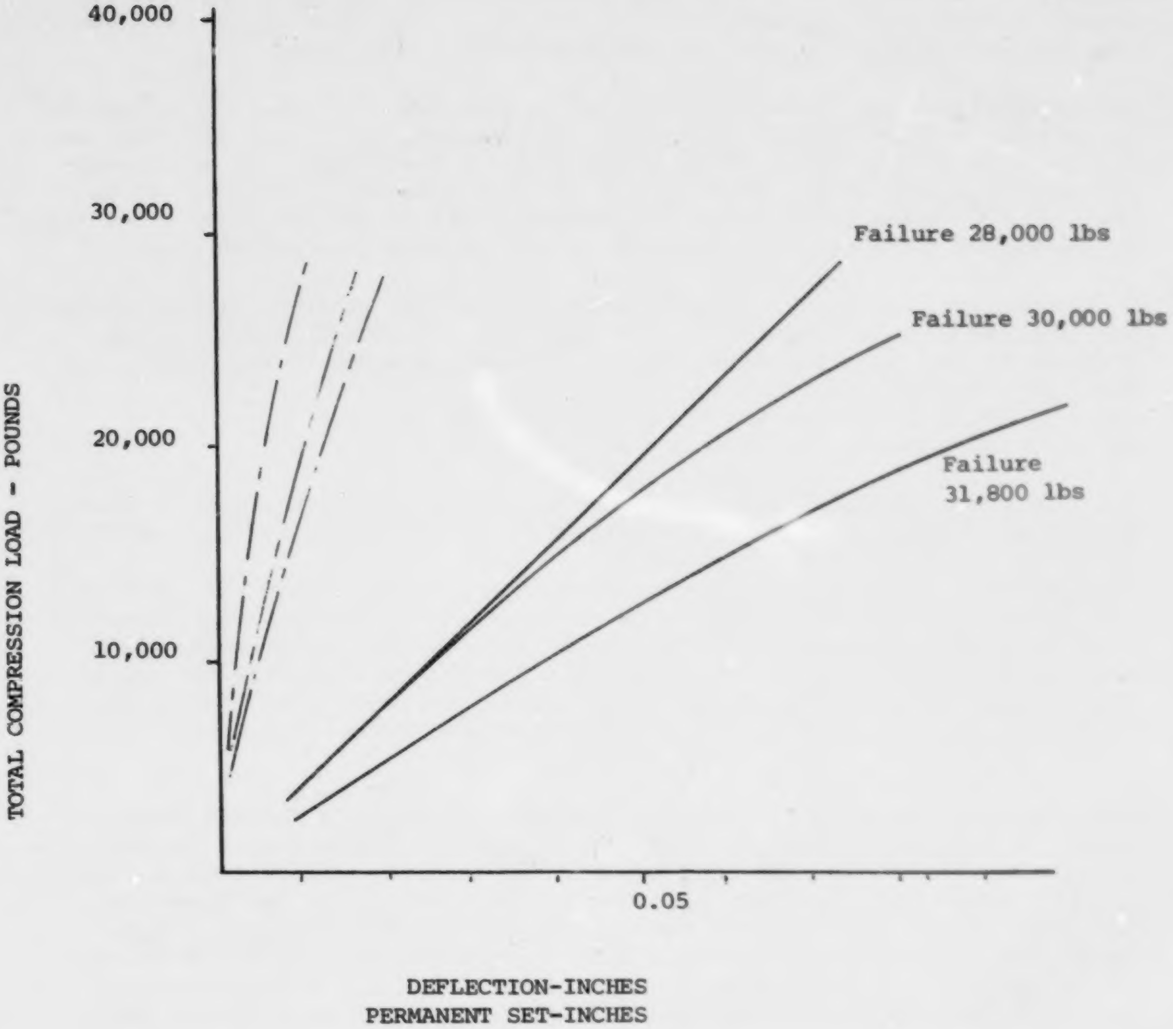


Figure 2-13. Compression load vs deflection and permanent set for a 4 ft X 8 ft rice hull foam fire wall.

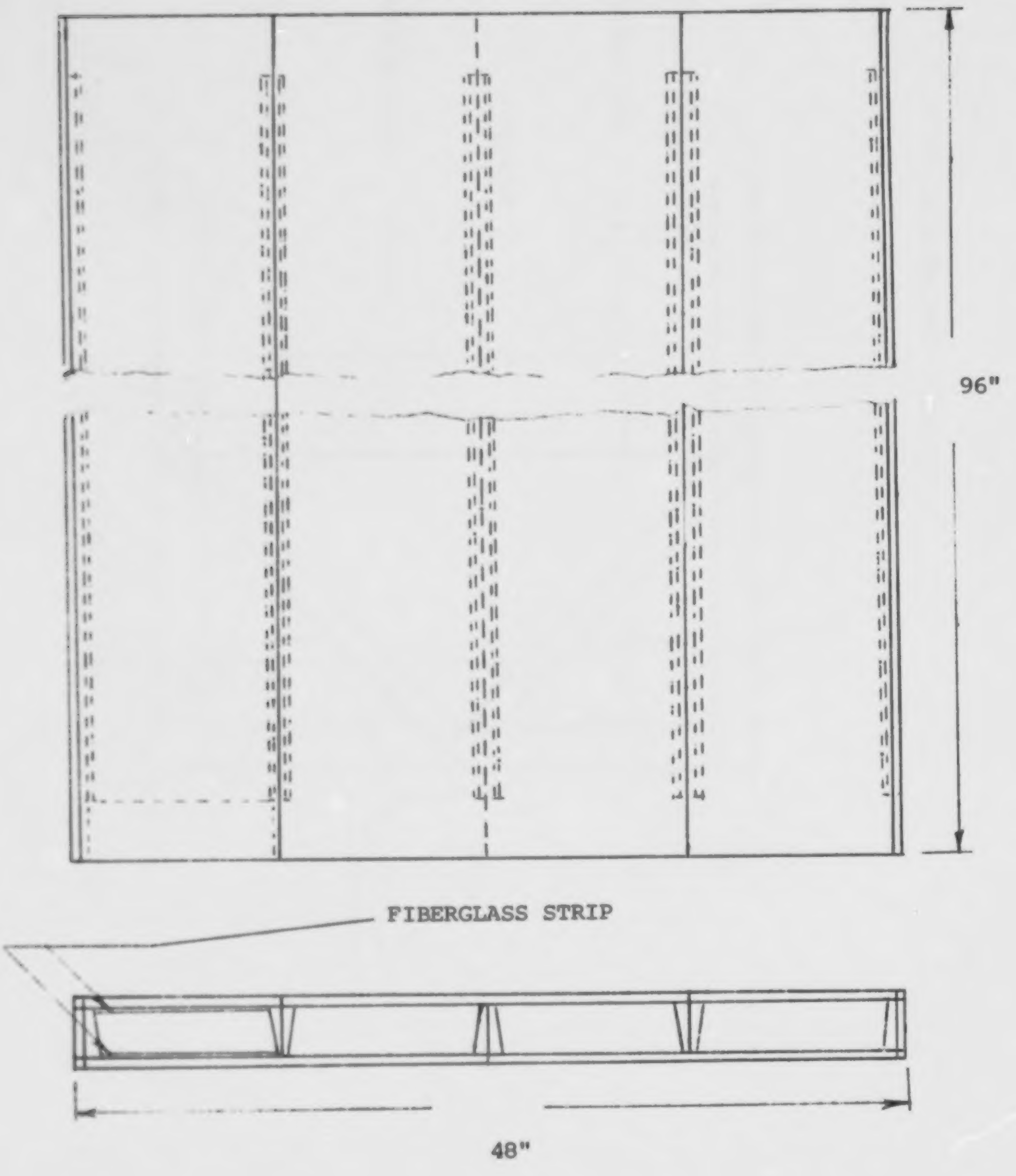

96"
FIBERGLASS STRIP
48"

Figure 2-14. Wall specimen.

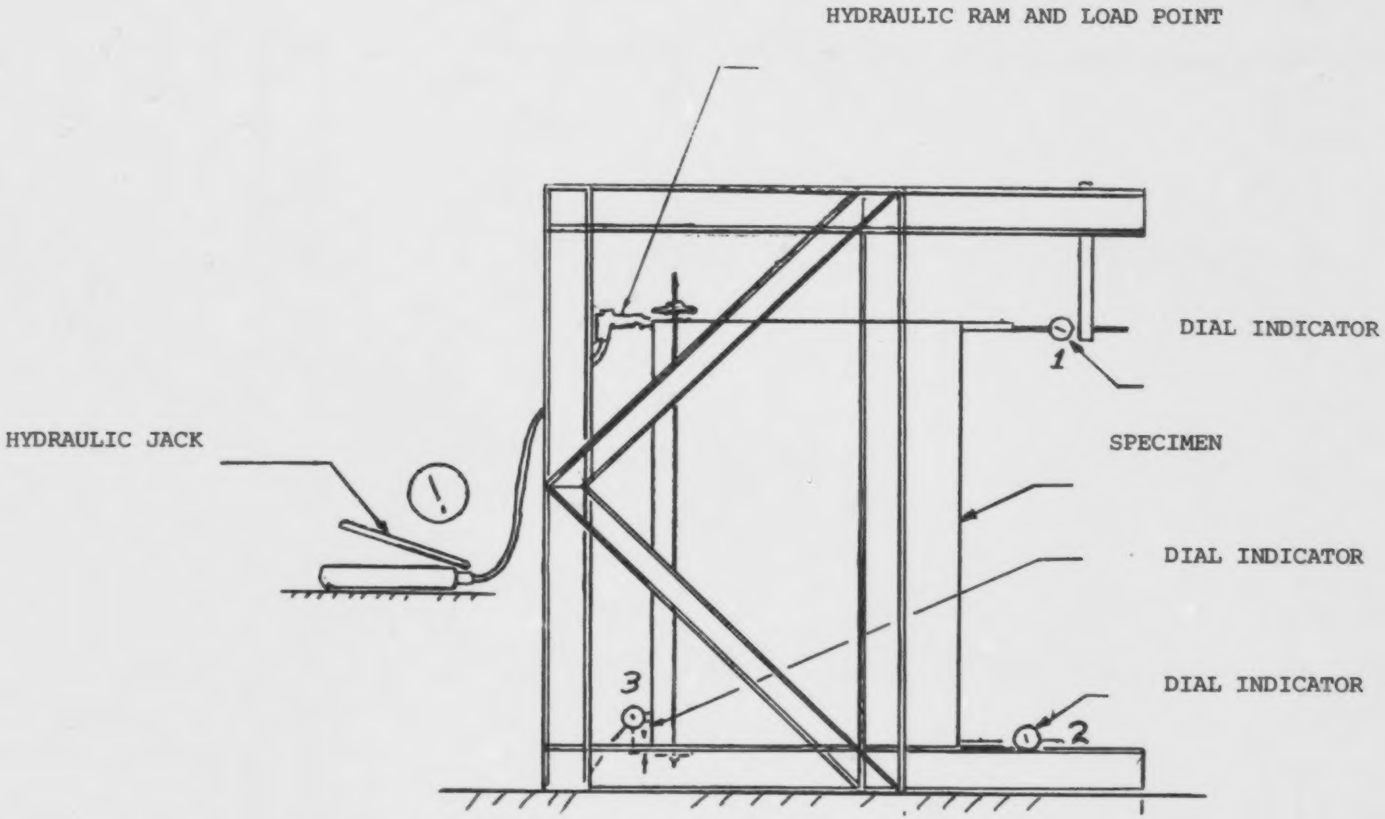

HYDRAULIC RAM AND LOAD POINT
DIAL INDICATOR
1
HYDRAULIC JACK
SPECIMEN
DIAL INDICATOR
DIAL INDICATOR
3
2

Figure 2-15. Material Systems Corp. panel racking shear test.

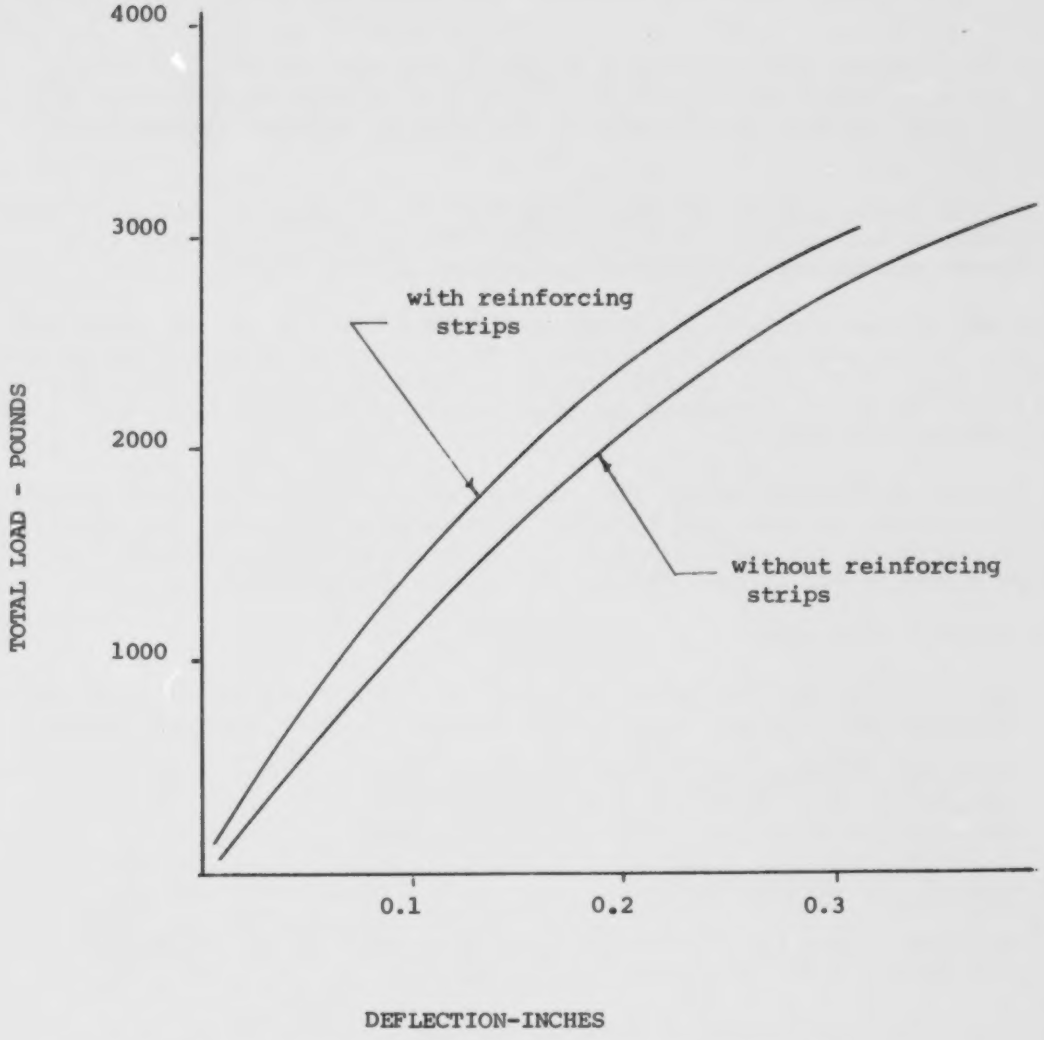


Figure 2-16. Racking shear test on panel without reinforcement.

A panel was again fabricated per Figure 2-14 without reinforcing strips and tested in racking shear. The results are presented in Figure 2-16. Although this panel provided results slightly lower (failure 48,000 pounds compared to 54,000 pounds and 1/8 inch deflection at 14,000 pounds rather than 18,000 pounds) the design values are still higher than that generally found in a 48 inch wide shear panel. Failure started with a slight crack in the lower tension corner which was reinforced with the fiberglass strip in the previous tests.

Based on the above results three more panels were fabricated under Testing Engineers'-San Diego observation per Figure 2-14 without reinforcement for testing under racking shear by them in the Material Systems Corporation's facility.

The racking shear loading was applied by means of a hydraulic system recently calibrated by Testing Engineers-San Diego. The panels were mounted in a test frame and deflection measured as outlined in ASTM E72-74.

Pre-loads of approximately 400 pounds were applied to the racking shear panels and dial gauges reset prior to testing. The loading was then applied to the racking shear test panels in 200 pound increments until failure occurred. After each increment of loading the load was returned to zero and set measurements were made.

The details of these tests are presented in Appendix C. Figure 2-17 presents the relationship of side load to deflection and permanent set. The qualifiable allowables are established on the lower of the values derived from ultimate load or at 1/8 inch deflection. These are discussed below.

(a) Ultimate Load Basis

The ultimate load has to be divided by a factor of safety of 3 and by the width of the panel to achieve a design allowable load per foot.

Panel #1: 3000 pounds/3 x 4 = 250 pounds/foot
Panel #2: 2800 pounds/3 x 4 = 233 pounds/foot
Panel #3: 3000 pounds/3 x 4 = 250 pounds/foot

(b) Load at 1/8 inch Deflection

The load at 1/8 inch deflection can also be used as the allowable provided it does not exceed that of the above.

Panel #1: 1,150 pounds/4 = 288 pounds/foot
Panel #2: 1,300 pounds/4 = 325 pounds/foot
Panel #3: 1,350 pounds/4 = 338 pounds/foot

The calibrated equipment was limited to a force of 3000 pounds which was not sufficient to fail two of the three qualification panels. However, the failure of one panel at 2,800 pounds would off set any higher loads developed by the two other panels.

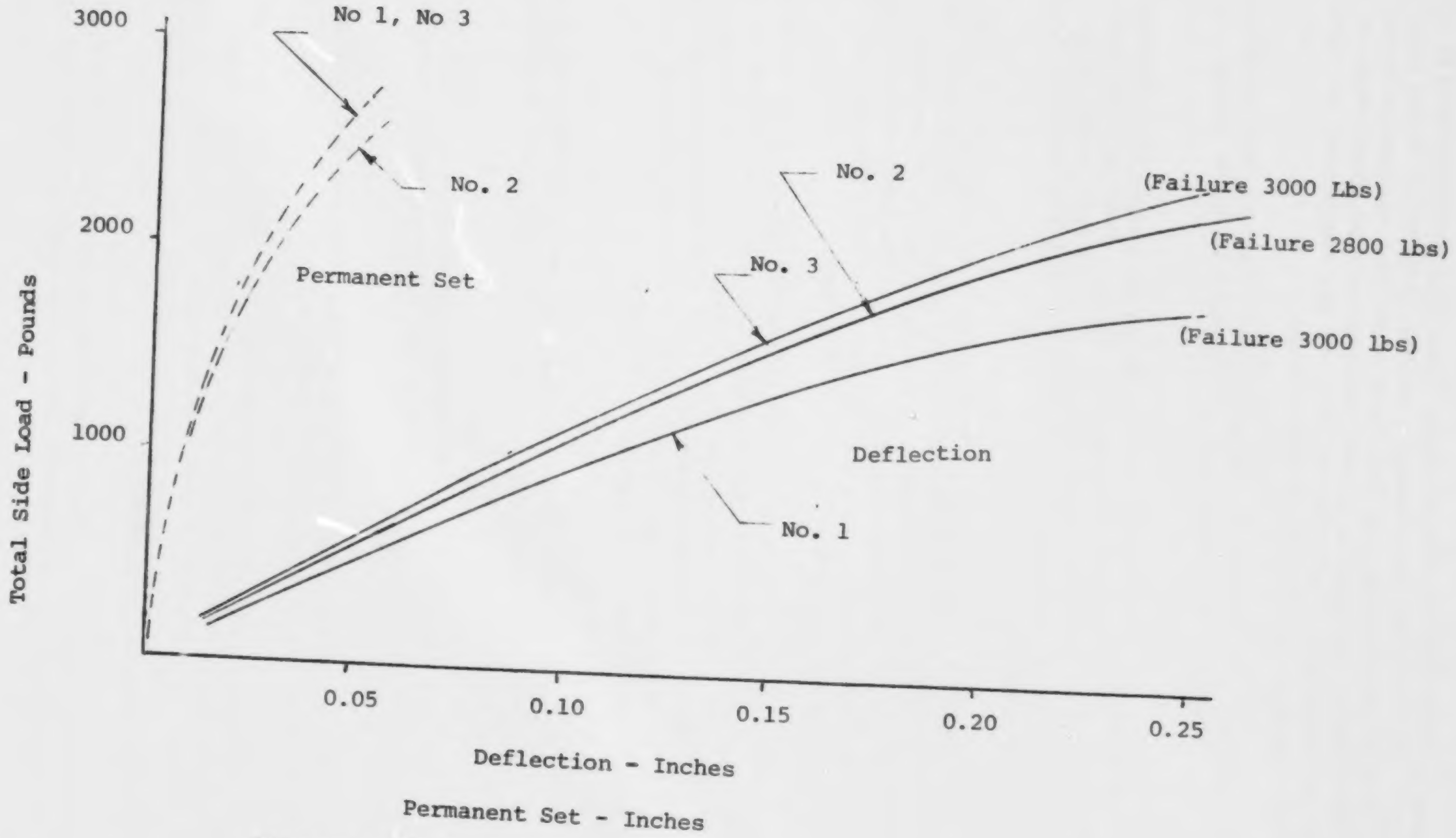


Figure 2-17. Racking shear load vs deflection and permanent set.

The load allowable that will be certified by ICBO will probably be 233 pounds per foot. The load can be raised by repeat testing of three more panels assuming that these three all fail in a close and similar pattern. However, the 233 pounds per foot is a very acceptable load when compared to standard constructed four foot wide walls. It is, therefore, not considered to be worth the expense to pursue this further.

The allowable based on deflection for panel #3 was close to that established by earlier tests. However, the other two values were 25 to 60 pounds per foot lower.

The allowable load based on ultimate failure at 2,800 pounds (233 pounds/foot) is lower than that determined by earlier tests. However, the earlier tests developed a crack at 3,000 pounds but still supported loads up to 4,800 pounds. This would indicate that the safest criteria would be to accept the 2,800 pounds as the limit.

Impact Load Test of Walls--These panels were fabricated per Figure 2-14 under the supervision of representatives from Testing Engineers-San Diego. Three panels were tested utilizing the testing techniques described in ASTM E-72 with the test specimen mounted horizontally. Three specimens rather than six (as indicated in ASTM E-72) were tested since construction of these panels is such that interior and exterior faces are the same.

Each test was conducted as follows: Initial drop of the 60 pound sand bag was made from a height of six (6) inches above the geometric center of upper panel face. Subsequent drops were made from increasing increments of six (6) inches until the panel being tested exhibited visual evidence of failure. Deflection readings were made after each one-half foot increment of drop. Set readings were made after each one-foot increment of drop. The results were as follows.

Panel No. 1: Maximum deflection was 0.65 inch and maximum set 1.85 inches. Failure was in the form of complete fracture through the panel section at a drop height of 2.5 feet.

Panel No. 2: Maximum deflection was 0.60 inch and maximum set 1.32 inches. Complete fracture through the panel section (at about mid-span) occurred at a drop height of 2.0 feet.

Panel No. 3: Maximum deflection 0.58 inch and maximum set 1.27 inches. Failure occured at a drop height of 2.0 feet.

Fire Rating--The resistance of the wall to fire was first evaluated at Material Systems Corporation with a small fire chamber. This chamber is capable of burning a 2 foot by 3 foot surface area of material. To save money, a section of the first floor panel tested was cut into a fire test specimen (2 Feet wide and 4 feet high).

This was designated panel #1. The surface had a crack in it from the beam test but was considered to be adequate for a fire test provided the uncracked surface was exposed to the fire.

The results from this test defined as #1 are presented in Figure 2-18. Unfortunately half way through the test it was determined that the cracked surface was exposed to the fire. This crack was observed through the furnace opening to separate at about one hour into the test causing what we believe the backside temperature to reach in excess of the allowable at one hour and fifty-five minutes.

A two foot wide by eight foot long section (see Figure 2-19) was taken from the undamaged part of a racking shear panel and designated panel #2. The results from this test designated as #2 are also shown in Figure 2-18. There were furnace difficulties which prevented the achievement of a full ASTM E-119 test. However, the results are conclusive enough to continue with a full scale two hour fire test. Specimen #2 was tested in compression after the fire test and failed at 3,000 pounds per linear foot. This is more than the qualifiable design load.

The results of this test indicated sufficient capability to proceed with a full-scale fire test.

Elements were produced for two 8 foot high by 12 foot wide walls and transported to the University of California Richmond Facility.* These elements were assembled into panels, and mounted into test frames, Figure 2-20. The endurance panel was instrumented with nine thermocouples as shown in Figure 2-21. It was placed in front of a furnace and loaded in compression to 1000 pounds per linear foot by hydraulic jacks shown in Figure 2-22. After 1 hour and fifty minutes of fire endurance testing per ASTM E-119, the panel lost ability to support load and the upper right hand thermocouple exceeded 250°F above ambient. This high temperature was caused by a crack in the back panel caused by the buckling in the upper right corner shown in Figure 2-22. The unexposed surface was otherwise intact. This premature buckling was caused by the inadequacies of the bond of the stiffeners to the back surface. This is shown clearly in Figure 2-23.

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* For further information see Fire Test Report: Fire Test of Material Systems Corporation's One Hour Load Bearing Wall Assembly. University of California, Berkeley, 1977.

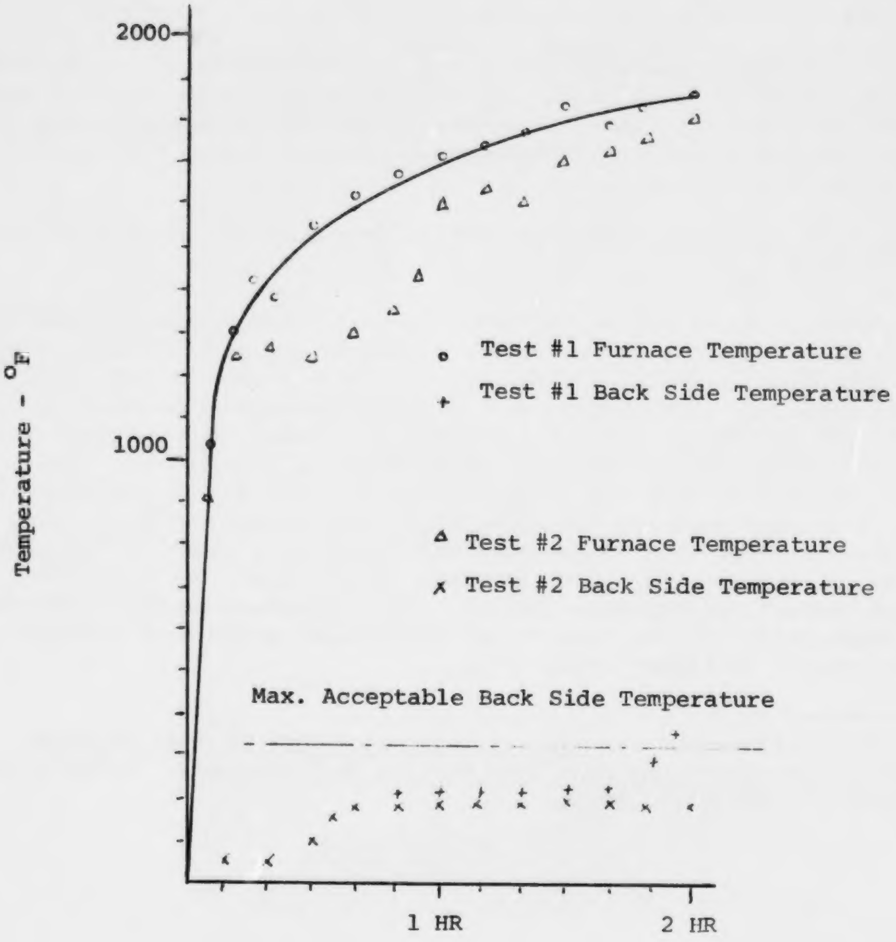


Figure 2-18. E-119 fire wall test.

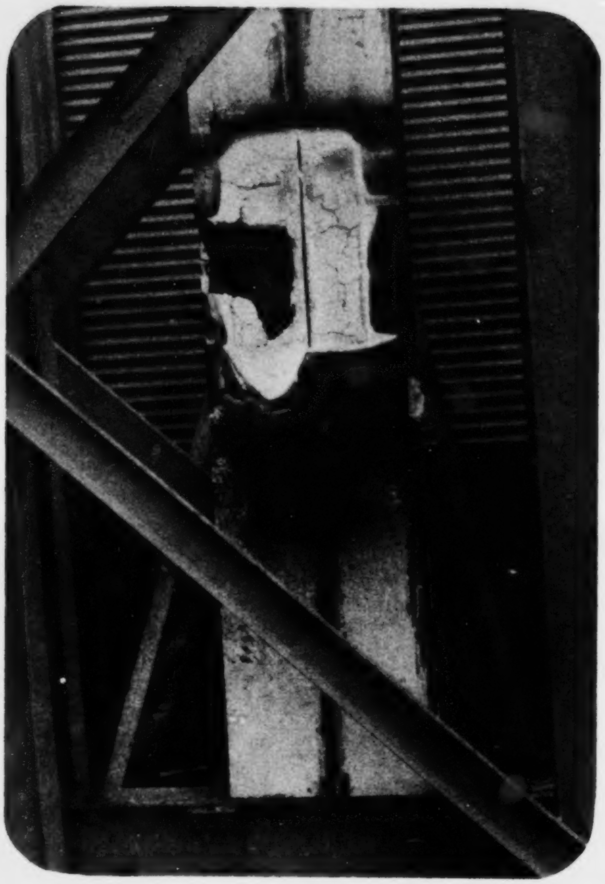


Figure 2-19. Small section fire test.

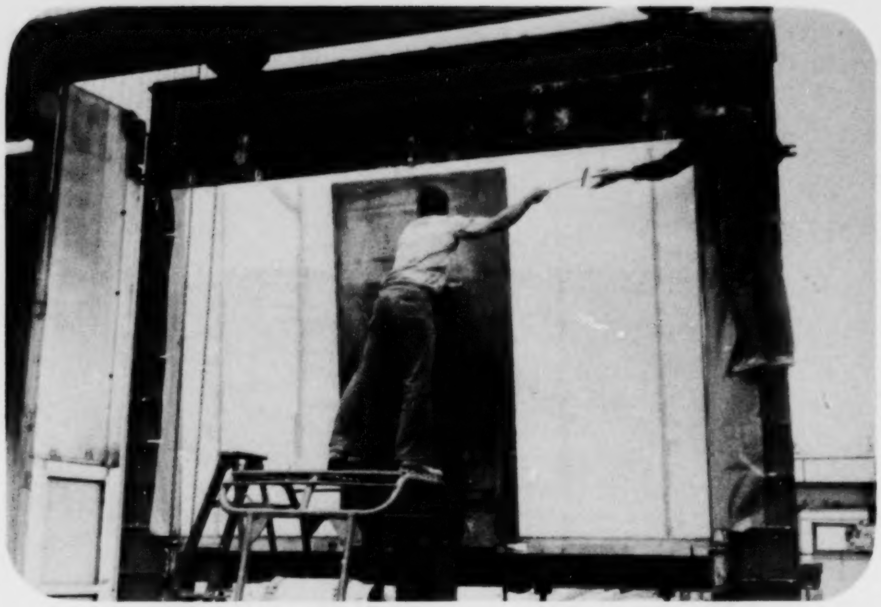


Figure 2-20. Mounting walls into test frame.

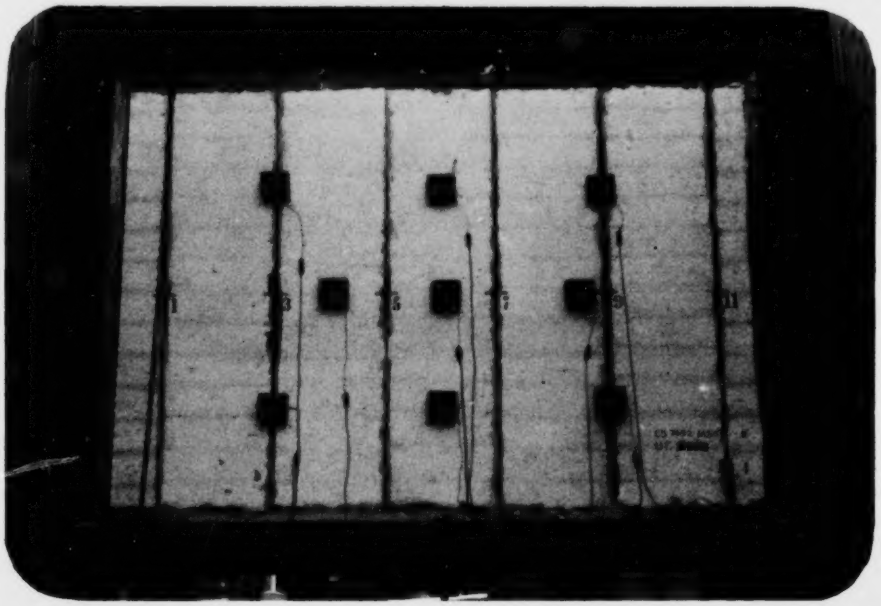


Figure 2-21. Instrumentation.

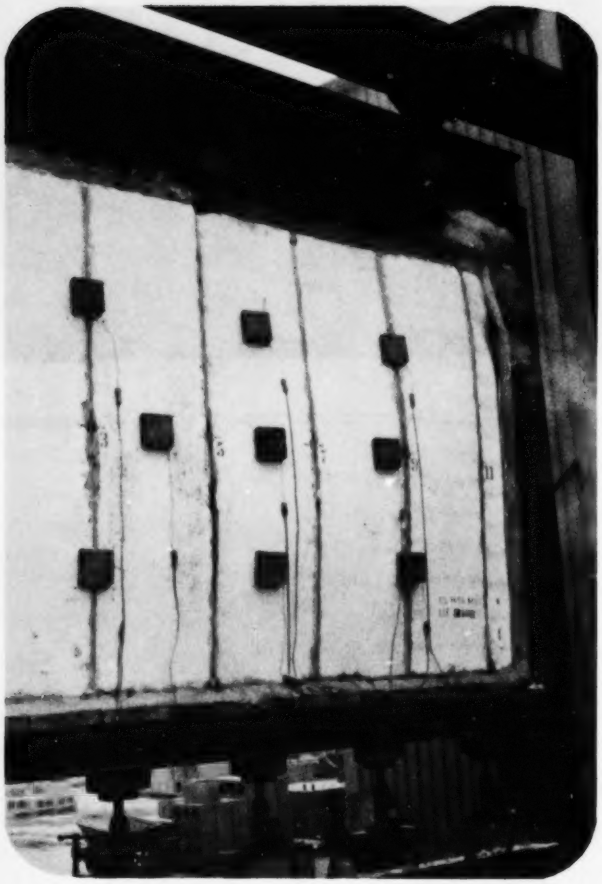


Figure 2-22. Buckling during endurance test.

Figure 2-23. Stiffener bond failure to unexposed surface.

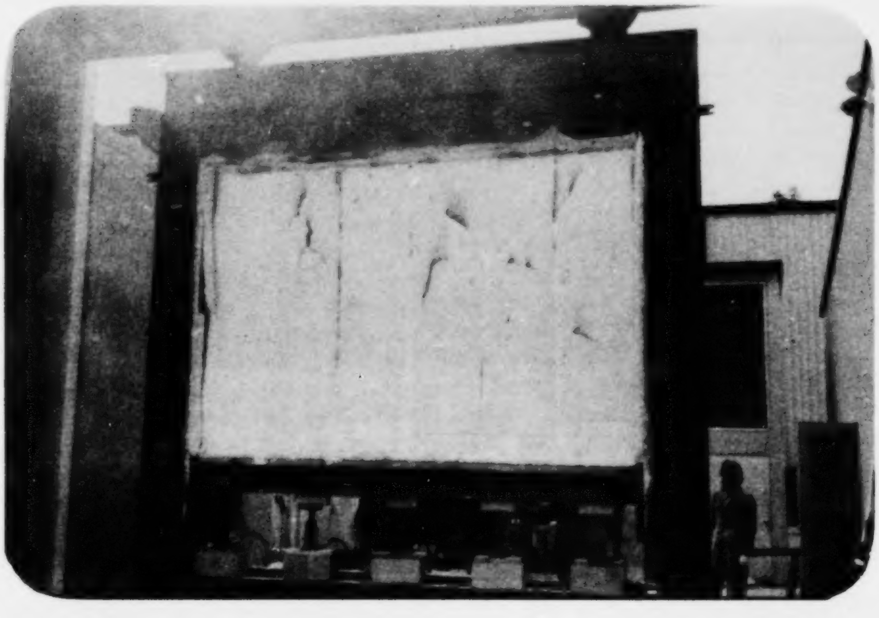


Figure 2-24. Exposed surface upon removal from furnace.

Since the endurance panel did not achieve two hours it was decided to attempt to qualify the wall for one hour by conducting a one hour rating hose stream test on the remaining panel. This test consists of running a fire endurance test for one half hour, spraying a hose stream over the surface for one minute and then increasing the load to twice that of initial loading.

Figure 2-24 shows the exposed surface of the panel upon removal from the furnace. Figure 2-25 shows the application of the hose stream. Figure 2-26 shows the wall appearance after the hose stream test and before increasing the load by a factor of two. Upon the increase of load, buckling failures, as shown in Figure 2-22, occurred at 1900 pounds per foot or 100 pounds less than required for qualification. This resulted from similar bond failures as that shown in Figure 2-23. From these tests, it was determined that a solution would be to increase the bond area of the stiffener. This is shown in Figure 2-27 in which these panels are being readied for a second fire test. Also a surface coat of magnesium oxy-chloride was applied.

Three panels, Figure 2-28, 8 feet by 12 feet were made for the second series of tests. The first panel was tested for a two hour rating hose stream test. This test consists of submitting the panel to the endurance test under load for one hour, applying a hose stream to the exposed surface, and then doubling the load. The previous panels tested were not coated which permitted the rice hull foam to vent any steam generated internally. This panel was coated and had no vents in the wall. When heated, the steam generated internally was sufficient to blow a section out of the panel. The test was continued, the hose stream penetrated the wall opposite where the segment was blown out.

The second panel was vented with 1/4 inch holes in the lower and upper plates and was tested as an endurance panel. The wall supported load for two hours and the highest backside temperature was 197°F which is considerably below the 320°F permissible.

The third panel was a repeat of the hose stream test for a two hour certification.

This test consists of submitting the wall to the fire under load for one hour, then removing it, submitting it to a hose stream, permitting it to dry, and then doubling the load. Upon testing, the hose stream penetrated the wall although it did sustain the load.

Review of the test specimen showed that the material did not receive sufficient heat to calcify the back surface. It is believed that stress concentrations were caused by the magnesium oxide chloride surface coat interaction with the plaster of the rice hull foam when it expands the surface. These stresses would be particulary high near the intersection of the surface panel and the rib. When impacted by the normal load from the fire hose, these combined stresses could be sufficient to cause localized failure.

A panel was fabricated using the modified surface coating application technique. This panel was subjected to and successfully passed the hose stream test for one hour fire wall qualification. A two-hour qualification is

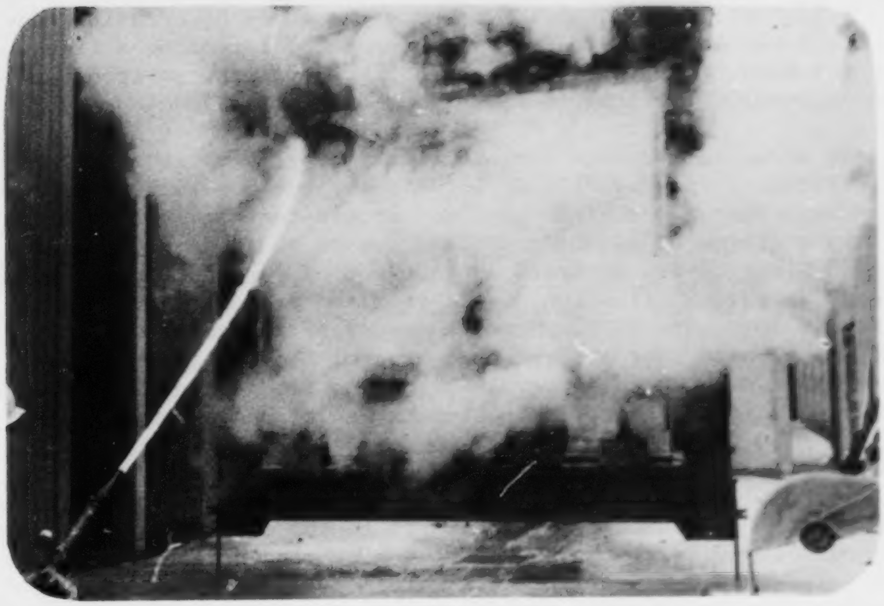


Figure 2-25. Hose stream test.

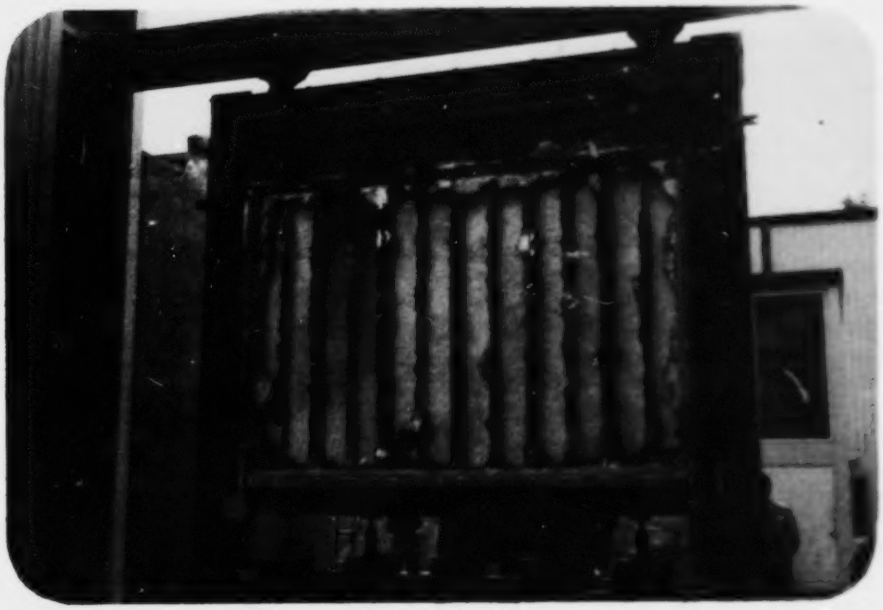


Figure 2-26. After hose stream test.

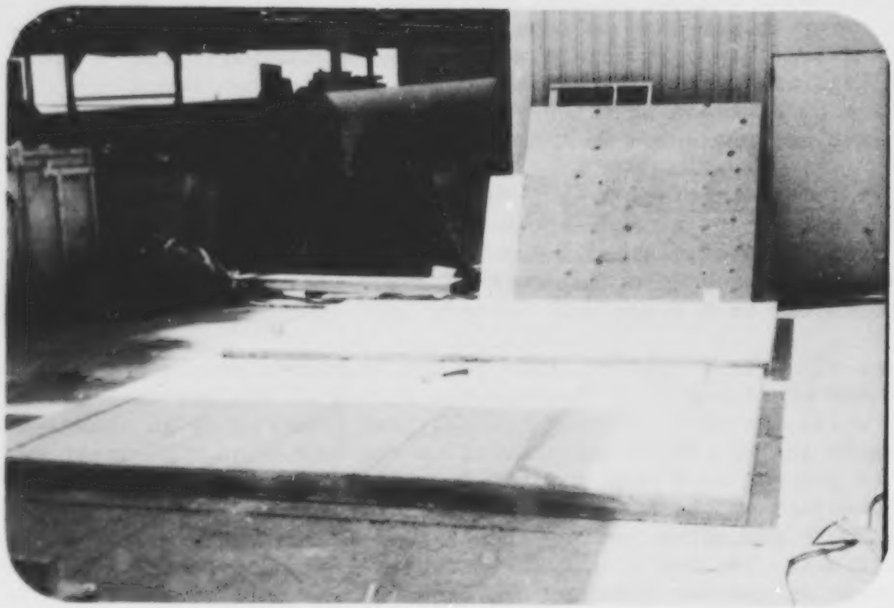


Figure 2-27. Panels with new rib.

Figure 2-28. Three panels ready for shipment.

possible but will require further full-scale testing at considerable expense. Since one hour is all that is required in 90% of construction, a two hour hose stream test study at this time does not appear warranted. Therefore, the wall will withstand a fire and support load for two hours but will permit penetration by a stream of water from a hose after one hour. Complete details on fir tests are presented in Appendix D.

Wall Thermal Characteristics--The test equipment used was the calorimeter shown in Figure 2-29, a Leeds-Northrup Speed-O-Max W recorder with 24 thermocouple probe readout, Shimadzu Model R-101 with 2 junction differential iron constant thermocouple, Adjust-A-Volt 230 volt variable auto transformer connected to 4 black body heaters, and iron-constantan thermocouples.

Tests were run with a uniform input to the heating elements and this was measured and monitored by a thermocouple placed on the hot face of the test specimen while the flow, of differential, was measured by an intermediate thermocouple in the center and another on the back side. The test was allowed to run for an 8 hour period where temperatures were marked at hourly intervals on the hour. At the end of this period a hot side temperature of 250°F was often reached and it is felt that this should be regarded as the extreme. The use of the differential thermocouple involved placing one junction on the hot side and the other on the cold side. The only other probe necessary was one adjacent on the hot side for obtaining an absolute temperaturewith the Leeds-Northrup equipment. The "U" value is computed by measuring the heat flow across the specimen for a given period. This resulted in an "U" factor of 0.073 BTU/(hr) (sq.ft) (°F) or an R of 13.7 for a waste panel as shown in Figure 2-8 without additional insulation.

Wall Manufacturing Technique--The configuration evaluated, Figures 2-5 and 2-6, was selected for the purpose of ease of production. This simple shape permits either casting or extrusion. For the purpose of this program casting was selected for economy reasons. During the course of production, experimentation with percentage of water was conducted to determine the effect of a dry viscous mix on strength as against a wet liquid mix. The ultimate strength was unaffected, only the drying time was greater with more water. The minimum amount of water required to react the plaster is prescribed in Table 2-1. The 90 minute plaster was used in this study to permit sufficient time for manual casting. Even with this plaster the part was handleable in 15 to 20 minutes. Limited experiments would indicate that normal plaster would permit handling in 20 to 5 minutes. This then opens two attractive possibilities for production.

The first and most readily available approach would be the utilization of the continuous concrete beam casting system. There are a multiplicity of these systems available and in use in the United States and elsewhere in the world. Any system that casts concrete can cast rice hull foam. The part should be cast on a tool reverse to that shown in Figure 2-7 with the tool surface textured to the desired surface characteristics of the part. This would eliminate the need for exterior finishing. The prototype production was done this way in order to control the critical dimension of the leg to the interior bond surface. This dimension can be controlled in

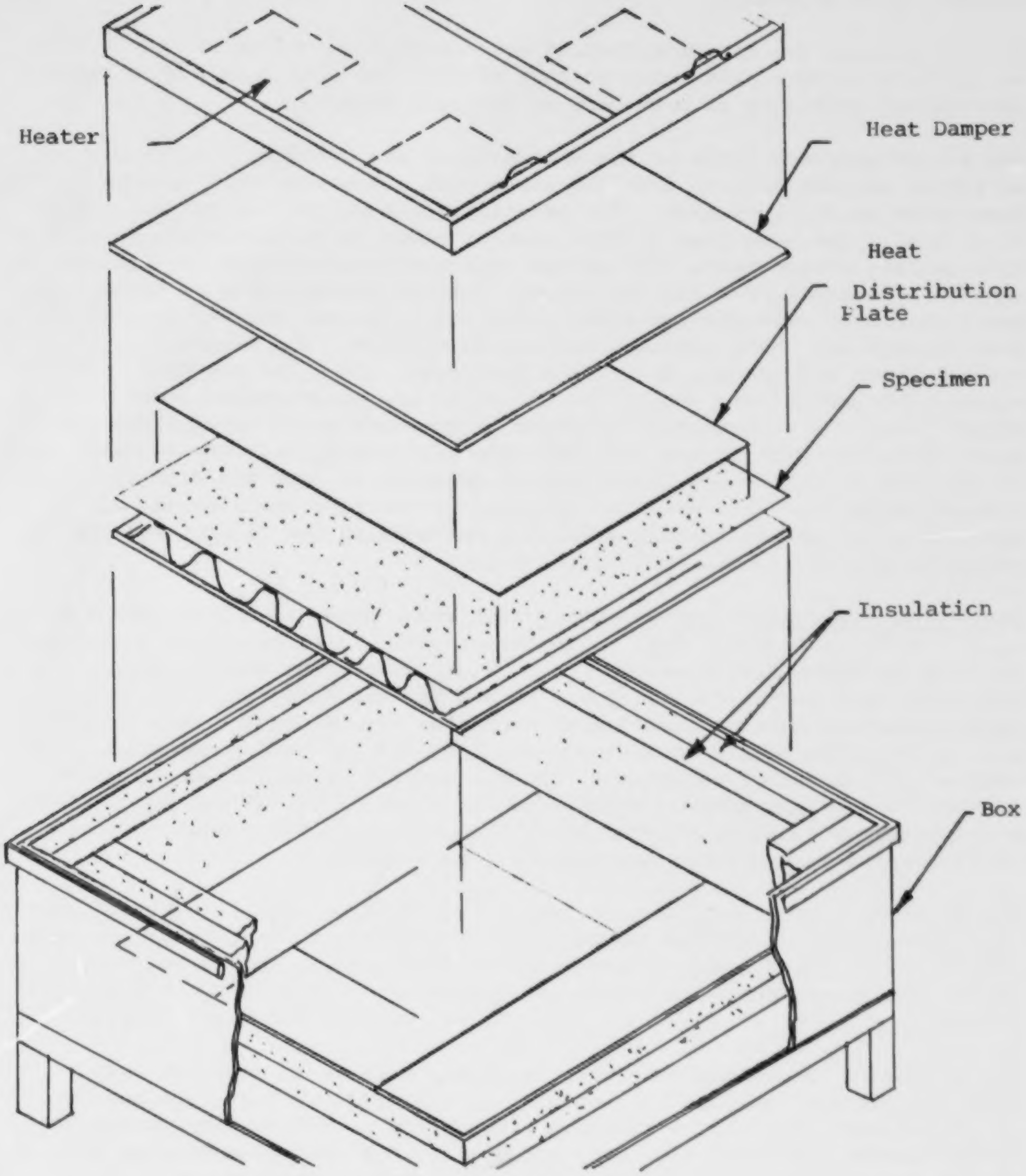

Heater
Heat Damper
Heat Distribution Plate
Specimen
Insulation
Box

Figure 2-29. Calorimeter.

a continous casting process by a sizing roller following the cast into the mold. The primary advantage of this process is that no machinery need to be developed. The only development costs would be the tooling and a limited process scale-up study.

In this process the exterior coating of magnesium oxy-chloride can be applied to the mold surface just prior to that of the rice hull foam. This permits dimensional stability as both cure at the same time.

The second approach would be the extrusion of the material. A dry mix would be forced through dies to form the shape onto a conveyor belt running at the same speed as the extrusion. The material would be cut and trimmed while still damp. The advantage of this process would be to accelerate production in a smaller environment. The second approach requires that the coating be applies separately from the extrusion. This is accomplished by first applying a thin seal coat without sand. This seals the surface and then the sand coat is applied. This approach reduces distortion. The disadvantage is that the equipment and process have to be developed. Once the elements shown in Figures 2-5 and 2-6 are available, the walls are assembled as shown in Figure 2-8. The recommended construction approach would be to stand the elements on one side of the wall onto the sill plate, nail the exterior skin to the sill plate and use the inorganic adhesive to bond the flanges of the element together. This would be followed by erecting the elements on the opposite side against the one completed and bonding the flanges and the two elements together as shown in Figure 2-8.

Wall Panel Application and Economics--The waste panel is a load-carrying wall. It has a two-hour fire rating which makes it an excellent partition wall for multiple family units. Table 2-4 presents the cost of such a partition wall installed. In order to provide the full two hours each exposed surface must be coated with magnesium oxy-chloride. This material acts as a weatherseal also although not required for this application. The cost of this material per square foot per surface is $0.111 as presented in Table 2-5. This makes a total cost installed of $0.922 per square foot. A conventional two-hour, fire-rated wall costs nearly twice that - a cost of $1.802 per square foot, see Table 2-6 for details.

The waste wall panel can also be used as an interior panel. Although load supporting ability and fire protection are not usually required, the availability of it is an added safety measure. The cost of the waste wall, $0.700 per square foot installed, is very competitive with the conventional interior wall cost of $0.76 per square foot, see Table 2-7 for details.

The waste wall panel can also be effectively used as an exterior wall. Although the load support is required, generally a 1/2 hour fire rating is considered adequate. A two-hour fire rating is definitely a positive safety factor. The exterior wall would utilize a cost of magnesium oxy-chloride on the weather exposed surface to act as a weather seal. This would result in a waste exterior wall cost of $0.811 per square foot. The conventional low cost exterior wall with one half hour fire rating would cost nearly 40% more or $1.137 per square foot installed (Table 2-8).

TABLE 2-4 COST OF WASTE PRODUCT TWO-HOUR, FIRE-RATED PARTITION WALL

Item	Material Cost	Labor Cost	Total Cost
Rice Hull Foam 9.656 lbs/ft^2 (\$0.038/lb)	$0.367	$0.076 *	$0.433
Glass Strands in Cap 0.031 lbs/ft^2 (\$0.35/lb	.011	Included above	.011
Adhesive 0.5 lb/ft^2 (0.103)	.052	Included above	.052
Assemble on Site: Four Sections (32 ft^2) Put in Place 16 min Apply Adhesive 8 min 24 min $\frac{11.52/hr}{60}$ 32 ft^2		.144 +	.144
Seal and Finish Joints	.020	.030 ‡	.050
Cost per ft^2 #	.450	.250	.700

[*] Estimate includes factory overhead, depreciation and labor and is based on MSC continuous production technology.

[+] Estimate made from observing demonstration model construction.

[‡] Estimate from Current Construction Costs, 1976 - Lee Saylor, Inc.

[#] Weather seal and upper and lower plates not included.

TABLE 2-5 MAGNESIUM OXY-CHLORIDE COATING COST/SQUARE FOOT

Item	Weight, lbs	Cost/lb	Cost
$MgCl_2 6H_2O$	0.36	$0.071	$0.026
MgO	.36	.135	.049
Sand	.36	.010	.036
Cost/ft^2	-	-	.111

TABLE 2-6 COST OF A CONVENTIONAL TWO-HOUR, FIRE-RATED PARTITION *

Item	Material Cost	Labor Cost	Total Cost
Double Stud Wall @ 16" O.C.	$0.146	$0.236	$0.382
Two Layers 1/2 in Fire X Sht. Rock Both Sides	.680	.680	1.360
Nails, Clips, and Misc Hardware	.060	-	.060
Cost/ft^2 +	.886	.916	1.802

* Current Construction Costs, 1976 - Lee Saylor, Inc.

+ Upper and lower plates not included.

TABLE 2-7 COST OF A CONVENTIONAL INTERIOR WALL *
(1/2 HOUR FIRE RATING)

Item	Material Cost	Labor Cost	Total Cost
Stud Wall @ 16" O.C.	$0.073	$0.118	$0.191
One Layer of 1/2 in Sheet Rock on either side	.220	.320	.540
Nails, Clips, and Misc Hardware	.030	-	.030
Cost/ft^2 +	.323	.438	.761

* Current Construction Costs, 1976 - Lee Saylor, Inc.

+ Upper and lower plates not included.

TABLE 2-8 COST OF A CONVENTIONAL EXTERIOR WALL *
(1/2 HOUR FIRE RATING)

Item	Material Cost	Labor Cost	Total Cost
Stud Wall @ 16" O.C.	$0.073	$0.118	$0.191
One Layer of 1/2 Inch Sheet Rock one side	.110	.160	.270
One Layer of Exterior Plywood one side	.142	.244	.386
Textured Coating	.180	.080	.260
Nails, Clips, and Misc. Hardware	.030	-	.030
	.535	.602	1.137

* Current Construction Costs, 1976 - Lee Saylor, Inc.

Recommendations and Conclusions-- The waste wall panel can be used competitively with conventional construction as a partition wall for multi-family units, as an interior panel and as an exterior panel.

The two-hour fire rating is a definite bonus for the latter two applications.

The major unknown factor is the effects of long-term loading. It is recommended that a Phase IV activity be initiated which will permit the evaluation of this phenomenon over a period of at least 3 years in three different environments.

SECTION 4

ROOF AND CEILING SYSTEM

Material Selection--The same rice hull foam used for the wall was selected (Table 2-1). First, it appeared to be the best of the formulation presented. Secondly, from a manufacturing approach, it is desirable to maintain the same formulation for as many products as possible.

Design Selection--For the purpose of this study the same design as the wall was selected. The time and funds available for this study precluded evaluating a multiple variation of configurations because each configuration required a new tool and a complete series of full-scale tests.

Flexural Strength of Roof and Ceiling System--Although the tensile strength of the material is low, it was decided to fabricate the first test specimen similar to the wall without any additional reinforcement. The specimen was built per Figure 2-30 and was tested in bending as shown in Figure 2-31 with pin-ended supports. Concrete blocks were placed uniformly on the surface. Blocks were used from the same production batch and weighed 25 ± 1/4 pounds each. The design load for roofs is 20 pounds per square foot and for floors 40 pounds per square foot. The major design criterion is that deflection does not exceed the span divided by 360, (1/360), when at design load. Maximum permissible deflection for an 8-foot span is then 0.267 inches. The first panel tested failed in lower skin tension at 28.4 pounds per square foot with a maximum deflection of 0.170 inches. The results are shown in Figure 2-32.

From the results of this test, it was decided to reinforce the lower skin with one layer of 1/2 inch square mesh hardware cloth (Hail Screen). This improved the strength of the panel considerably. The panel failed at a load of 105 pounds per square foot. The deflection at 20 pounds per square foot was 0.055 inches and at 40 pounds per square foot 0.108 inches, both considerably less than the allowed 0.267 inches. This would indicate that a reduction in cross-section or an increase in span length would be acceptable.

Long-Term Loading on Roof Panel--The next aspect to be considered for a floor or ceiling system is the effects of long-term loading on the panel. The panel was loaded at a level of 21.9 pounds per square foot. The panel was supported on blocks as shown in Figure 2-33 to more closely simulate the end conditions that exist in a housing system. The beam maintained this loading over a period of 68 days with readings taken as indicated in Figure 2-34. The 20 pounds per square foot loading condition for a roof is a combination of loads that may occur in a specific region. These include combination of wind and snow. The 21.9 pounds per square foot loading for a period of 68 days is a rather severe

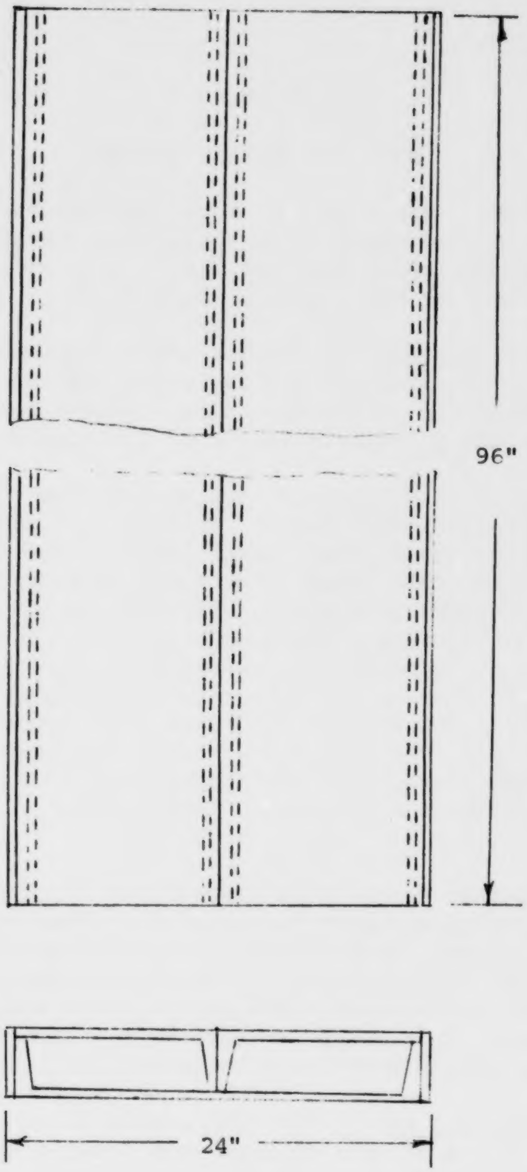


Figure 2-30. Floor and ceiling specimen.

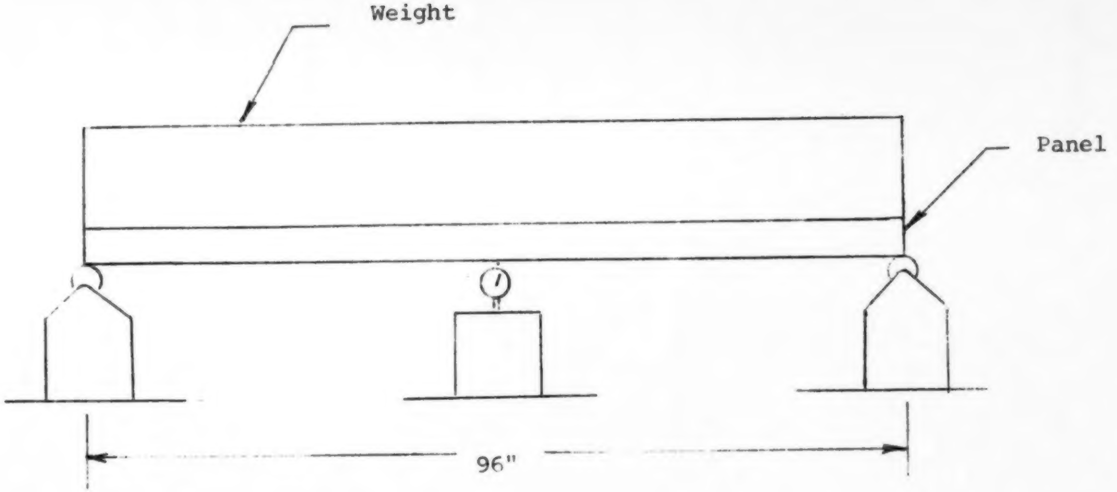

Weight
Panel
96"

Figure 2-31. Beam-bending test.

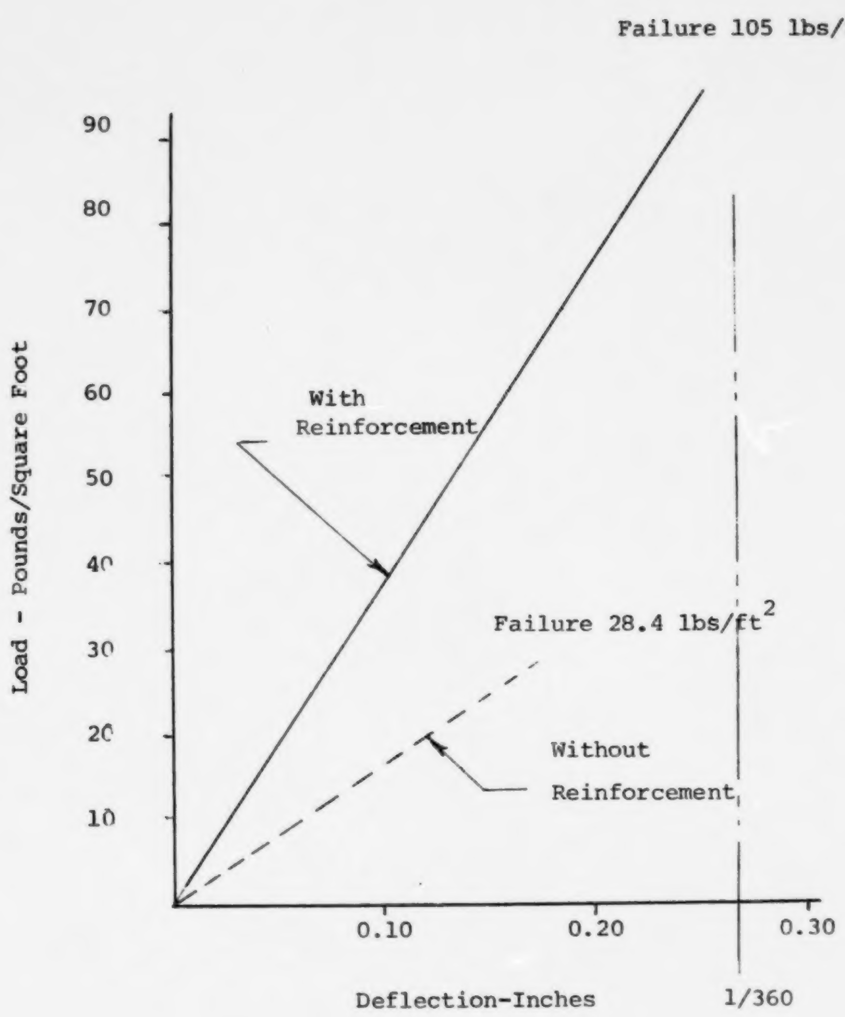


Figure 2-32. Beam-bending vs deflection.

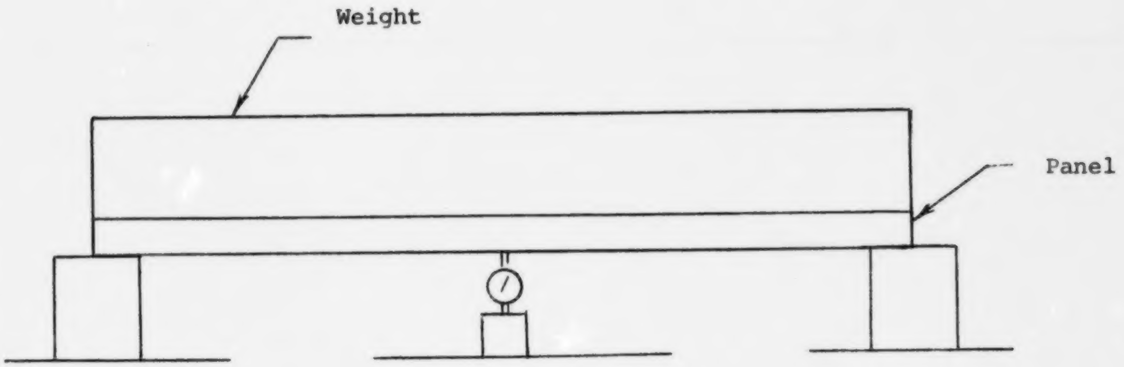

Weight
Panel

Figure 2-33. Beam-bending test (long-term loading).

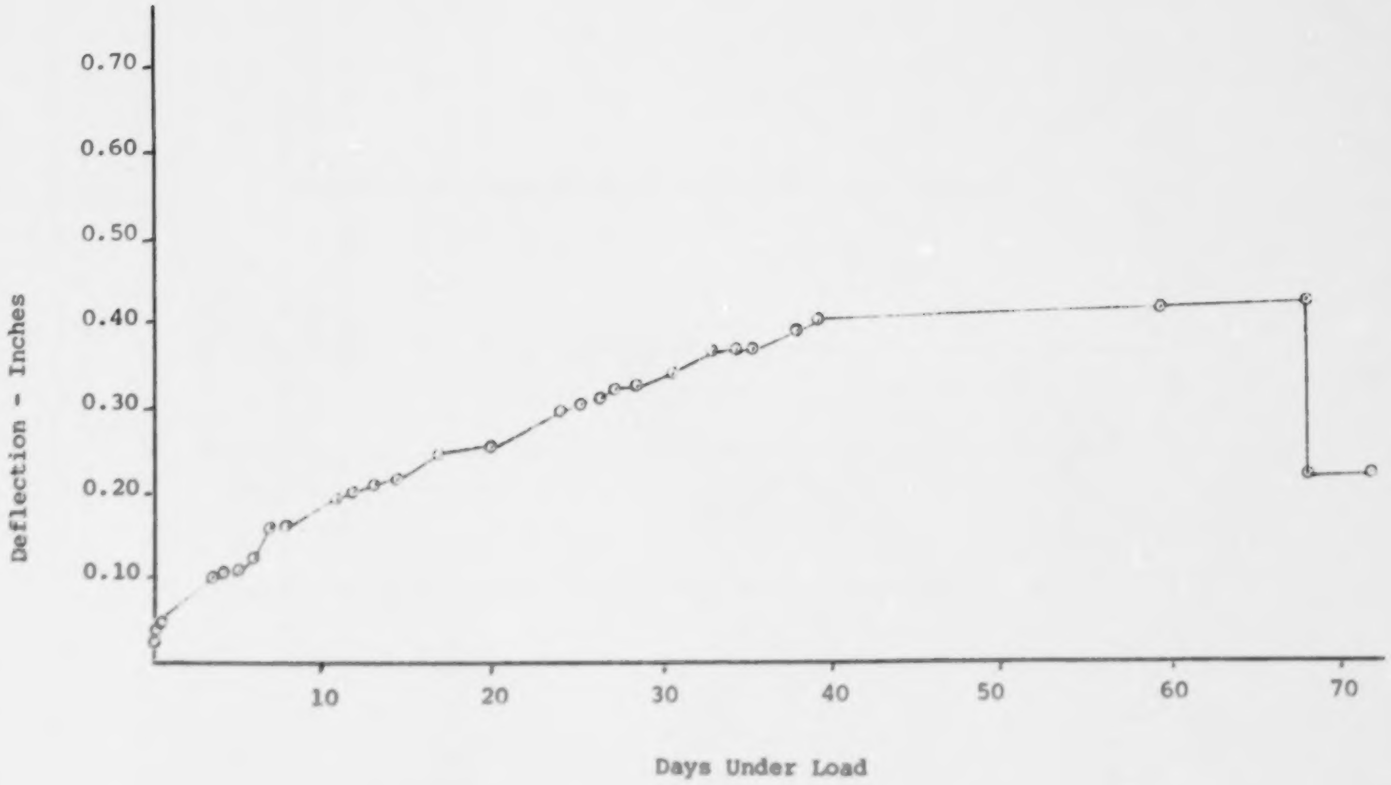


Figure 2-34. Long-term loading test: Uniformly loaded 21.9 lbs/ft^2 beam bending dry.

evaluation. The primary purpose here was to determine the creep characteristics of the material. As can be seen from Figure 2-34, the deformation rate was as follows:

Days	in/day
0 - 6	0.020
6 - 39	0.007
39 - 68	0.002

The rate came close to leveling out after 39 days.

Removal of the load indicated an initial set of 0.220 inches. After a period of 6 days there were no changes.

The results of this study indicate that this panel would be acceptable in non-snow climates where the maximum load is intermittent. However, in a snow climate additional reinforcement would be required.

Effects of Water on Long-Term Loading--It was decided to run an equivalent test with the loaded panel subjected to a complete inundation of running water. The panel was tested as produced without surface coats. The results were that the bond at "A", Figure 2030, deteriorated losing the beam effect and placing the lower skin in pure tension causing failure in 24 hours. This has resulted in a study of the effect of water on the waste product's bond.

This long-term test was severe but was designed to provide a rapid evaluation of the suitability of the waste materials for structures. A load level of 10 to 13 pounds per square foot would be more realistic and the rate of water flow should be sharply reduced.

A review of the joints of the previous specimen tested under running water indicated a failure of the substrate below the inorganic adhesive. It was felt that an epoxy adhesive would penetrate the substrate further and provide a better joint.

A panel was then manufactured with epoxy bonded joints and again without surface coating. A load of 10.9 pounds per square foot was determined to be more near a realistic loading. Figure 2-35 shows the results of this test to date. The panel showed a decrease in deflection rate after four days. At the end of 5 days the water was turned off and the panel unloaded to determine the extent of permanent deformation. After four days of no load or water the permanent deflection appeared to be 0.283 inches. However, the panel was still damp and more recovery may have been possible.

It was decided to reload the specimen and start the running water. The slope of the deflection curve the second time appears to be slightly more than that of the first time.

After three days, the load was removed and the water turned off. The panel did not recover this time immediately. After three days, it recovered to a

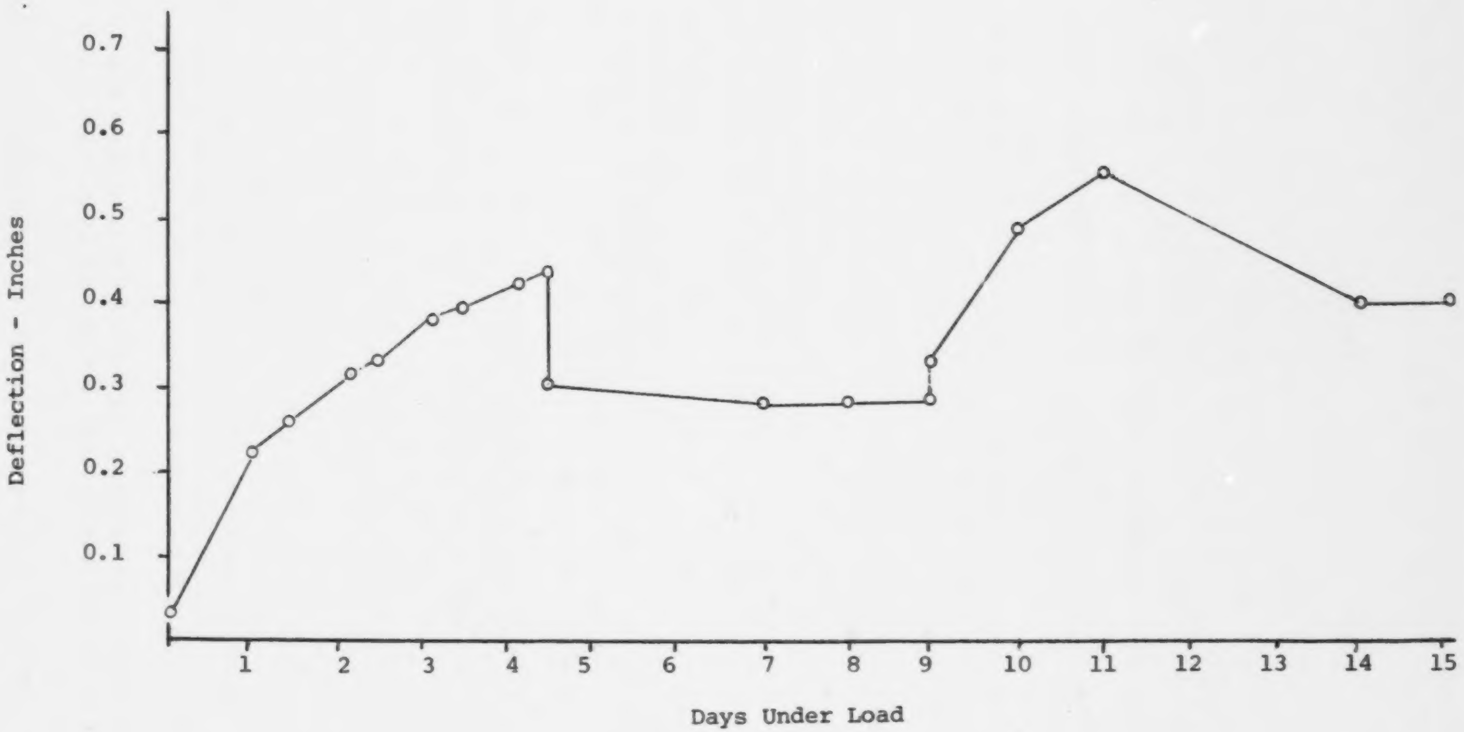


Figure 2-35. Uniformly loaded 10.0 lbs/ft^2 beam-bending running water. Days - Under Load

deformation of 0.40 inches and then stablized with no further recovery.

Surface coatings would assist the material appreciably and further studies should be conducted on the protection of these panels from running water.

Roof Panel Manufacturing Technique--The same techniques recommended for the wall would be applicable for the roof panel. The reinforcing is an additional complication. If an extrusion process is used, the reinforcement would have to be inserted in advance of the die. The hardware cloth is provided in rolls which permit ease of feeding. If metal lath is used, it is rigid and would have to be pre-cut to length and inserted incrementally into the dies.

If a casting process is used, the reinforcement would be installed into the mold prior to the casting of the rice hull foam.

Roof Panel Product Application and Economics--The major application explored here was for a load supporting roof with the lower surface used as the ceiling. The assembly technique would be to install all the lower reinforced sections on the roof first. Then the upper non-reinforced sections would be bonded to the lower reinforced section creating a structure similar to that shown in Figure 2-8.

The economics of the waste roof panel as a roof/ceiling combination are presented in Table 2-9. This compares favorably with the cost of conventional construction presented in Table 2-10.

The waste roof panel, if used as a ceiling would use only the lower elements, Figure 2-5, bonded together. Since there are no loads involved other than dead load, no reinforcement would be required in the elements. The economics of such a waste system are presented in Table 2-11. This compares favorably with the cost of conventional construction presented in Table 2-12.

Recommendation and Conclusions for Roof and Ceiling Systems--The rice hull foam creates an acceptable roof-ceiling combination system, as well as an acceptable ceiling system. The major concern is the effects of long term loading with and without water on the product. As can be seen in Figure 2-36, the panel under a short duration load is more than adequate when the tension side is reinforced. However, the same panelloaded under a typical 21.9 pound per square foot roof load showed considerable creep for the first 6 days and then showed a tendency to stablize although not completely. A loading condition of this magnitude for such a long period is highly improbable. However, the creep characteristics of the material in tension has been indicated. Improved reinforcement is required.

Running a similar long-term loading with the addition of running water over the sample indicated further concern. It is doubtful that water would be be running over an unprotected panel for five days but the test does indicate some sensitivity to the effects of water.

TABLE 2-9 COST OF WASTE PRODUCT ROOF-CEILING PANEL WITH HARDWARE CLOTH AND METAL LATHE REINFORCEMENT

Item	Material Cost	Labor Cost	Total Cost
A. Hardware Cloth Reinforcement:			
Rice Hull Foam 9.656 lbs/ft^2 (\$0.38/lb)	\$0.367	\$0.076 [*]	\$0.443
Glass Strands in Cap 0.31 lbs/ft^2 (\$0.35/lb)	.011	Included above	.011
Hardware Cloth 0.5 ft^2 (\$0.1783/ft^2)	.089	Included above	.089
Adhesive 0.5 lb/ft^2 (0.103)	.052	Included above	.052
Assemble Four Sections (32 ft^2) on Site			
Put in Place 16 min			
Apply Adhesive 8 min			
24 min $\frac{11.52/hr}{60}$ 32 sqft^2	-	.144 [+]	.144
Seal and Finish Joints [‡]	.020	.030	.050
Cost/ft^2	.539	.250	.789
B. Metal Lathe Reinforcement:			
A Above without Reinforcement	.450	.250	.700
Lathe Reinforcement 0.5 ft^2 (\$0.14/ft^2)	.007	-	.007
Cost/ft^2	.457	.250	.707

[*] Estimate includes factory overhead, depreciation, and labor and is based on MSC continuous production technology.

[+] Estimate made from observing demonstration model construction.

[‡] Weather seal not included.

TABLE 2-10 COST OF CONVENTIONAL ROOF-CEILING SYSTEM

Item	Material Cost *	Labor Cost *	Total Cost *
2 x 4 Joists	$0.126	$0.188	$0.314
Plywood Exterior	.142	.149	.291
Sheet Rock, Hang, Tape & Texture	.120	.160	.280
Cost/ft^2 +	.388	.497	.885

* Estimates from Current Construction Costs, 1976 - Lee Saylor, Inc.

+ Weather seal not included.

TABLE 2-11 COST OF WASTE PRODUCT CEILING PANEL

Item	Material Cost	Labor Cost	Total Cost
Rice Hull Foam 4.828 lbs/ft^2($0.038/lb)	$0.183	$0.038 *	$0.221
Glass Strands in Cap 0.016 lb/ft^2($0.35/lb)	.006	Included above	.006
Adhesive 0.25 lb/ft^2($0.103)	.026	-	.026
Assemble Four Sections (32 ft^2) on Site			
Put in Place 16 min			
Apply Adhesive 8 min			
$24 \text{ min} \frac{11.52/\text{hr}}{60} 32 \text{ ft}^2$	-	.144 +	.144
Finish Joints	.010	.015 ‡	.025
Cost/ft^2	.225	.197	.422

* Estimate includes factory overhead, depreciation, and labor and is based on MSC continuous production technology.

+ Estimate made from observing demonstration model construction.

‡ Estimate from Current Construction Costs, 1976 - Lee Saylor, Inc.

TABLE 2-12 COST OF CONVENTIONAL CEILING SYSTEM

Item	Material Cost *	Labor Cost *	Total Cost *
2 x 4 Joists	$0.126	$0.188	$0.314
Sheet Rock, Hang, Tape & Texture	.120	.160	.280
	.246	.348	.594

* Estimates from Current Construction Costs, 1976 - Lee Saylor, Inc.

In summary, the waste panel can be used for a roof-ceiling combination system. However, it should use the steel lathe reinforcement rather than the hardware cloth. It is not only less expensive but will provide more stiffness. In addition, it is suggested that reinforcement be incorporated into the compression side as well as the tension side. This would reduce the potential for creep. A weather seal such as a composition roof cover, a built up roof cover, or any conventional weather seal system should be applied to the exposed surface of the panel. The ceiling system can be used as is for a non-loaded system.

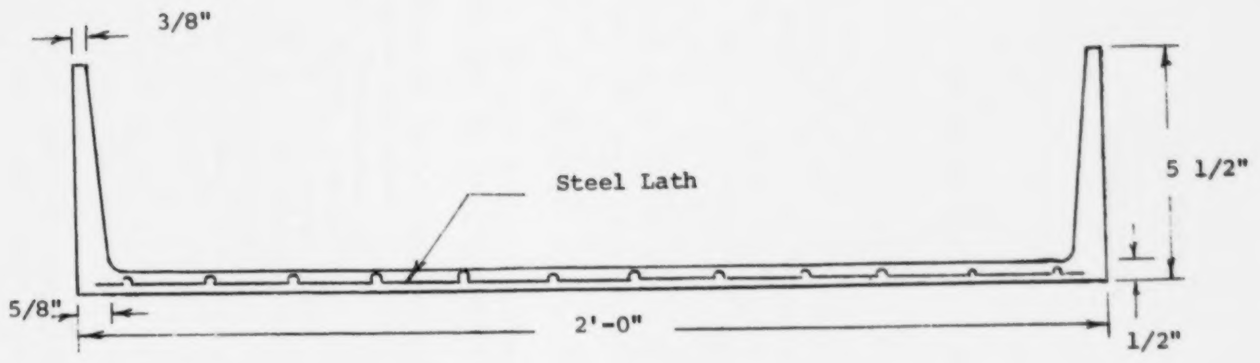

3/8"
Steel Lath
5 1/2"
5/8"
2'-0"
1/2"

Figure 2-36. Elements for a floor panel.

SECTION 5

FLOOR SYSTEM

FLOOR SYSTEM

Material Selection--The same rice hull foam used for the wall and roof was selected (see Table 2-1).
Design Selection--The floor performs similar to the roof only under high loads. Therefore, the same design was selected.
Flexural Strength of Floor Panel--The tests run for the roof were load extended to include floor requirements. Figure 2-32 shows that the floor is more than adequate for short duration 40 pound per square foot floor loads. Under this loading condition an even longer floor span could be considered.
Long Term Floor Panel Loading-The long term loading effects of the panel used as a floor can be evaulated from Figure 2-34. This test definitely indicates a problem with the present design. It is therefore proposed to increase the element depth to 5 1/2 inches to provide additional stiffness. This will increase the stiffness by a factor of 2.4. This also reduces the tensile load on the elements surface by 1.6. It is also proposed that metal lath reinforcement be placed in both surfaces. For details see Figure 2-36.

This additional stiffness and reduction in tensile stress should improve the long term load carrying capability of the material.

Effects of Water on Long Term Loading-- There is no doubt that from the test data shown in Figure 2-35, it will be necessary to protect the material from long periods of running water. It is recommended that both surfaces be sealed. Water of evaporation will have minimal effect. It is only prolonged inundation such as an undetected plumbing leak that would be a problem.
Wear Surface--The exposed rice hull foam surface was used as the wear surface in the initial phases of the demonstrated module construction. As in most foam type materials the rice hull foam does not wear well. It must be covered with a wear surface. The minimal acceptable surface would be a tile. However, it would be more preferable to coat the surface with one quarter inch of magnesium oxy-chloride cement. This is an elastic type material which does not crack easily and also provides the needed water seal.
Floor Panel Manufacturing Technique--The same techniques as described for the roof panel are applicable for the floor panel. If the casting process is used, the magnesium oxide chloride cement surface can be cast ahead of the rice hull foam permitting a one step production. If the extrusion process is used the magnesium oxide chloride would have to be cast on the element as a secondary step.

Floor Panel Application and Economics--The primary application for the waste floor panel would be for a floor-ceiling system. The panel could also be used for a floor system but would have less economic advantage. The basic panel produced from elements shown in Figure 2-36 would cost installed $0.728 per square foot. See Table 2-13 for details. A one quarter inch magnesium oxy-chloride wear surface would add $0.220 per square foot (see Table 2-14) increasing the total cost to $0.948 per square foot. This compares extremely well with a conventional floor ceiling system itemized in Table 2-15.

There is still a competitive edge for the waste panel as a floor panel when compared with a conventional wood system (see Table 2-16). Their cost compares well with a concrete slab of $1.10 per square foot.

Recommendation and Conclusions for the Floor-Ceiling or Floor Panel System--The system has definite advantages both for economic and fire safety reasons in this application. However, the long term loading characteristics of the system have not been completely determined. The same concern as expressed for the roof application applies here. Certainly the increased panel depth and reinforcement in both surfaces would help. However, it is still necessary to evaluate the long term problems over at least a six month period and preferably over a three year period before using the material for a floor-in application.

TABLE 2-13 COST OF WASTE PRODUCT FLOOR-CEILING PANEL WITH METAL LATHE REINFORCEMENT

Item	Material Cost	Labor Cost	Total Cost
Rice Hull Foam 10.208 lbs/ft^2 ($0.038/lb)	$0.388	$0.076 *	$0.464
Glass Strands in Cap 0.031 lbs/ft^2 ($0.35/lb)	.011	Included above	.011
Lathe Reinforcement 0.5 sq ft($0.14 sqft)	.007	-	.007
Adhesive 0.5 lb/ft^2 (0.103)	.052	Included above	.052
Assemble on Site: Four Sections (32 sq ft) Put in Place 16 min Apply Adhesive 8 min 24 min $\frac{11.52/hr}{60}$ 32 sqft		.144 +	.144
Seal and Finish Joints	.020	.030 ‡	.050
Cost/ft^2 #	.478	.250	.728

* Estimate includes factory overhead, depreciation and labor and is based on MSC continuous production technology.

+ Estimate made from observing demonstration model construction.

‡ Estimate from Current Construction Costs, 1976 - Lee Saylor, Inc.

# Wear Surface not included.

TABLE 2-14 COST OF MAGNESIUM OXY-CHLORIDE FLOOR SURFACE

Item	Weight, lbs	Cost/lb	Cost
$MgCl_26H_2O$	0.72	$0.071	$0.051
MgO	.72	.135	.097
Sand	.72	.010	.072
Cost/ft^2			.220

TABLE 2-15 COST OF CONVENTIONAL FLOOR-CEILING SYSTEM

Item	Material Cost *	Labor Cost *	Total Cost *
2 x 6 Joists	$0.200	$0.290	$0.490
1/2 inch C-D ext. Plywood	.142	.131	.273
1/2 inch Fire X Sheet Rock	.120	.160	.280
Misc. Hangers and Hardware	.060	-	.060
Cost/ft^2 +	.522	.581	1.103

* Estimates from Current Construction Costs, 1976 - Lee Saylor, Inc.

+ Wear surface not included.

TABLE 2-16 COST OF CONVENTIONAL WOOD FLOOR SYSTEM

Item	Material Cost *	Labor Cost *	Total Cost *
Same as Table 2-15 Less Sheet Rock	$0.402	$0.421	$0.823
Vapor Seal	.050	.020	.070
Cost/ft^2 +	.452	.441	.893

* Estimates from Current Construction Costs, 1976 - Lee Saylor, Inc.

+ Wear surface not included.

SECTION 6

FIRE DOOR

Material Selection for Core- The initial work on the fire door core was based on rice hull foam formulation RH-54 developed in Phase II of this program. This formulation is presented in Table 2-17. This formulation when used to construct the fire door was found to be difficult to work because: (1) rapid setting which made preparation and casting of 2.5 ft^3 of mixture required for a fire door core extremely difficult, (2) a density which was too high, and (3) cost somewhat over present materials for fire door cores. When this formulation was used on laboratory size specimens, the rapid set-time could be readily accomodated.

One other scale-up problem was that a specimen 6 inches by 6 inches was readily handleable, even wet, once setting occured. However, a full-scale door core measures 34.5 inches by 77 inches by 1.5 inches. When wet, the cast material will crack on handling because of the high weight (water present prior to drying) and long unsupported distance of cast panel.

It was necessary to reformulate so as to accomodate processing, properties and price requirements. Several approaches were used and these were:

1. Reduce density by use of styrofoam beads

2. Increase processability by use of beads because of processability and ease of movement to fill the mold

3. Achievement of 1 & 2, above, by foaming

Table 2-18 lists a series of formulations which were made and evaluated in the laboratory. This evaluation was accomplished by exposing each specimen to a propane torch kept 3 inches from the front surface and a thermocouple to the rear face. It must be commented that the propane torch provides a highly erosive action not present in the standard fire test. The use of comparative results and performance of a "standard" material made this test useful for screening.

The data showed that direct replacement of rice hulls by styrofoam beads caused thermal insulation to be unsatisfactory and the most logical reason being the great distance in density from 40.9 pounds per cubic foot.

TABLE 2-17 RH-54 FORMULATION

Rice Hulls	100g
1" Chopped Glass Fiber	15g
MSC Additive	40g
Gypsum Plaster	60g
Casting Plaster	240g
Water	225g

Formulation #2 has aluminum hydrate added to provide extra water as possible way to improve insulative performance. This was very effective without too great an increase in density but large increase in cost. In Formulation 3 & 4, the aluminum hydrate was replaced by an even more efficient source of water, aluminum sulfate. This has 48.6% water as sompared to 34.0% for aluminum hydrate and 21.0% for hydrated gypsum.

The incorporation of aluminum hydrate provided improved insulative performance and this was due to the ability of this material to provide water for transpirational cooling. Assuming this to be correct, new addition of a compatible material having a higher water content might give still further improvement. For this purpose, $Al_2(SO_4)_3\ 18H_2O$ was selected.

TABLE 2-19 FIRE-DOOR INSULATION MATERIAL FORMULATIONS BASED ON RICE HULLS

	Formulation						
Item	1	2	3	4	5	6	7
Water	330	350	330	340	360	350	360
90 min. Casting Plaster	450	450	450	450	450	450	450
MSC Proprietary Binder	60	60	60	60	-	-	-
Styrofoam Beads	5	5	-	-	-	5	-
Rice Hulls	75	75	150	150	150	75	150
$Al_2O_3\ 3H_2O$	-	164	-	-		164	100
$Al_2(SO_4)_3 18H_2O$	-	-	50 *	50 *	50	-	50
1/2" Chopped Glass	-	-	-	-	3.5	-	3.5
G-3300 (Surfactant)	-	-	-	-	3.5	3.5	3.5
Density, lbs/ft^3	20.5	26.2	37.3	26.4	27.4	28.6	28.6
Cost, $\$/ft^3$	0.875	1.517	1.712	1.138	1.915	1.208	1.739
Max. Temp, $^{\circ}F$ after 2 hrs	Failed ‡	300	225	Failed ‡	404	475	235
Formulation	8	9	10	11	12	13	14
Water	360	360	350	425 *	425 *	350	330
90 min. Casting Plaster	450	450	450	450	450	450	450
MSC Proprietary Binder	-	-	-	-	-	-	-
Styrofoam Beads	-	-	-	-	-	-	15
Rice Hulls	150	150	150	12.5	12.5	150	150
$Al_2O_3\ 3H_2O$		-	-	-	38	-	-
$Al_2(SO_4)_3 18H_2O$	50	50	50	12.5	12.5	50	50
1/2" Chopped Glass	3.5	-	3.5	3.5	3.5	3.5	3.5
G-3300 (Surfactant)	3.5	3.5	3.5	3.5	3.5	3.5	-
Density, lbs/ft^3	28.5	27.2	33.9	33.0	33.3	33.0	26.8
Cost, $\$/ft^3$	1.038	0.584	0.940	0.796	0.964	0.958	0.919
Max Temp, $^{\circ}F$ after 2 hours Failed $^+$	340	335	155	185	250	300	285

See notes on following page.

TABLE 2-18 (Continued) FIRE-DOOR INSULATION MATERIAL BASED ON RICE HULLS

[*] Added a solid: All following formulations use 33% solution, thus 150 g sol'n contains 50G $Al_2(SO_4)_3 18H_2O$.

[+] Reached 600 F in 28 mins with rapidly increasing rate of heat-up.

[‡] Reached 435 F in 20 mins and rising very rapidly.

[#] Water added to make up for that lost because of less amount of $Al_2(SO_4)_3 18H_2C$ solution used.

Addition of this compound to a water-plaster mixture caused setting to occur in about 15 minutes even though 90 minute casting plaster was used. What was unanticipated was a 75% increase in volume due to frothing. It appears as if other additions are needed to prevent cracking or drying of the foam. The glass fibers and/or rice hulls used in the formulations should prevent cracking.

The same frothing and rapid set was obtained when regular wall plaster was used.

Frothing can not occur between aluminum sulfate and calcium sulfate. The presence of calcium carbonate in the plaster reacts with the acidic aluminum sulfate to generate carbon dioxide, more calcium sulfate and aluminum hydroxide (alumina trihydrate). So use of aluminum sulfate adds water for cooling and forms two other materials which also help in insulation because of water content.

Formulation 5 was adequate for 2 hour use, with a large decrease in cost but with very satisfactory density. Formulation 6 and 7 are too expensive but Formulations 8 thru 14 all are acceptable.

It was decided that further evaluation had to be made on full scale door cores. Initially it was decided to case the core into an upright mold.

Modifications to Formulations 5 and 14 from Table 2-18 were used to cast five cores. These are presented in Table 2-19.

It was obvious from this work that the panels were not drying on the bottom and were so wet as to cause fracture when moved, support of underside during movement might prevent this. Frothing could also cause weakening, so "B" was made without detergent. There was now insufficient material to fill the mold. Slight increase in detergent gave better results for formulations C, D, and E but results were still not satisfactory.

It was decided to do further refinement on Formulation E with a specimen 24 inches by 32 inches. This size provided scale up data, permitted E-119 fire test evaluation and used less time and materials.

The processing difficulties from rapid set time were overcome by use of a protein retarder and it became possible to fabricate specimens having a material density of about 28-32 lb/ft^3. An E-119 fire test in which face temperatures were increased (by increment) to 1800°F demonstrated complete protection for a period of 90 minutes as evidenced by failure of cotton linters or Kleenex to ignite when pressed agianst the back surface during the test.

The maximum recorded back-side temperature was 340°F. After 90 minutes, the test specimen was placed at a 20 foot distance from a fire hose with a 1.5 inch nozzle and hit with a stream of water at 30 psi for 8 seconds; the door maintained its integrity despite the erosion of material to a depth of about 1.0 inch.

The above evaluation resulted in the selection of the formulation presented in Table 2-20.

TABLE 2-19 ATTEMPTS TO CASE FULL SIZE FIRE DOOR CORE (34.5" x 77" x 1.5")

Constituent	Formulation				
	A	B	C	D	E
Rice Hulls	8978	8978	8978	9427	9427
1/2" Glass	209	209	209	219.5	219.5
90 min. Casting Plaster	26933	26933	26933	28280	28280
Water	20948	20948	25436	26708	26708
$Al_2(SO_4)_3 18H_2O$ Sol'n	8978	8978	2244	2356	2356
Detergent	80	0	25	26.3	26.3

TABLE 2-20 FORMULATION FOR FIRE DOOR CORE *

Item	%
Rice Hulls	13.7
1/2 inch Chopped Glass Fiber	0.6
90 min Casting Plaster	41.1
MSC Binder	3.13
Water	38.0
$Al_2(SO_4)_3 18H_2O$	3.4
Detergent	0.04
Retarder	0.03

* Density - 32 pounds per cubic foot
Stablized Moisture Content - 10%

Material Selection for Framing Members--The framing material has screw retention requirements as well as fire resistance requirements. The density of this material is no longer critical since the volume of material needed for a frame is small compared to the core.

The first experiments were carried out to compare plaster, magnesium oxy-chloride and magnesium oxy-sulfate with phenolic microballoons which impart lower density and helps nail and screw retention. Results are summarized in Table 2-21.

These data indicated the weakness of plaster and superiority of magnesium oxy-chloride.

The three binder materials were then compared to a fibrous material prepared from Douglas Fir bark, called Silvacon, assuming this would help values using plaster. Results are presented in Table 2-22. Use of Silvacon improved the properties of plaster over phenolic microballons but are still inadequate for the application. The magnesium oxy-chloride again displayed far superior results and adequate properties for framing material.

It was decided to continue formulations with magnesium oxy-chloride in place of plaster but to investigate other filler materials derived from waste materials. Since Silvacon is produced from a scrap material (Douglas Fir Bark) and is inexpensive, it was included in the study.

A variety of formulations were evaluated with the various waste materials and magnesium oxy-chloride. Results are summarized in Table 2-23. The properties that resulted from use of Douglas Fir fibers gave excellent results even when the bulk of this material was replaced by waste-derived Silvacon (see Formulation 1). Actually this mixture of fillers gave highest all around strengths. Since the use of Douglas Fir fibers was so successful it was tried with plaster, Formulation 5, and gave poor properties. Formulations 3 and 4 were made with 90 mesh sand added to increase density since nail and screw retention improved with density but with plaster this improvement fell far too short. Magnesium oxy-chloride and milled rice hulls, Formulation 6, provide nearly an equivalent product to Formulation 1.

Mechanical tests were conducted on wood materials used for frames. These results are presented in Table 2-24. As can be seen the 455 pound screw retention capability of inorganic mix #1 and the 445 screw retention capability of inorganic mix #6 are as good as or superior to that of the wood.

One additional problem was noted when eight foot long sections were fabricated: low flexural strength. To improve this characteristic untwisted sisal strands were incorporated into the mix. This resulted in the selection of the material formulation presented in Table 2-25.

TABLE 2-21 COMPARISON OF MATRIX MATERIALS FOR DOOR FRAMING USING PHENOLIC MICROBALLOONS

	Formulation		
Item	1	2	3
$MgCl_2 6H_2O$	93.5 g	-	-
H_2O	70.5 g	95 g	175 g
MgO	100.0 g	100 g	-
MSC Binder	10.0 g	-	-
$MgSO_4 7H_2O$	-	66 g	-
Casting Plaster	-	-	275 g
Phenolic Microballons	30.0 g	30 g	30 g
Density, lb/ft^3	56	59	58
Nail Pull, lbs	Not nailable	22	Not nailable
Screw Pull, lbs	235	63	32

TABLE 2-22 COMPARISON OF MATRIX MATERIALS FOR DOOR FRAMING USING SILVACON

	Formulation		
Item	1	2	3
$MgCl_2 6H_2O$	93.5 g	-	-
H_2O	80.5 g	95	175 g
MgO	100.0 g	100 g	-
$MgSO_4 7H_2O$	-	66 g	-
MSC Binder	15.0 g	-	-
Casting Plaster	-	-	275 g
Silvacon	75.0 g	75 g	75 g
Density, lb/ft^3	82	81	61
Nail Pull, lbs	395	Not nailable	29
Screw Pull, lbs	435	88	94
Compression, psi	3100	1350	-

TABLE 2-23 USE OF VARIOUS WASTE FILLERS FOR DOOR FRAMING USING MAGNESIUM OXY-CLORIDE

	Formulation					
Item	1	2	3	4	5	6
$MgCl_2 6H_2O$	93.5 g	93.5 g	-	-	-	93.5 g
H_2O	70.5	70.5	175 g	175 g	175 g	70.5
MgO	100.0	100.0	-	-	-	100.0
Regular Rice Hulls	-	35.0	-	-	-	-
=5 Milled Rice Hulls[*]	-	-	-	60 g	-	40.0
Douglas Fir Fibers[+]	25.0	25.0	-	-	50 g	-
Silvacon	50.0	-	60 g	-	-	40.0
Sand	-	-	125 g	125 g	-	-
MSC Binder	-	10.0	-	-	-	-
Casting Plaster	-	-	275 g	275 g	275 g	-
Density, lb/ft^3	74	69.5	74	86	69.5	81.0
Nail Retention lbs	225	200.0	15	65	35.0	-
Screw Retention lbs	455	360.0	100	130	85.0	445.0
Compression, psi	3250	1350.0	500	500	530.0	2400.0

[*] Hammer-milled rice hulls, contains about 33% (wt) of - 20 mesh fines.

[+] From Industrial Paper Company, Longview, Washington. Screened to remove -20 mesh fines.

TABLE 2-24 PROPERTIES OF VARIOUS WOODS USED IN DOOR FRAMES

Sample	d	%H_2O gain	Compression, psi Dry	Compression, psi Wet [*]	Screw Retention lbs Dry	Screw Retention lbs Wet [*]	Nail Retention lbs Dry	Nail Retention lbs Wet [*]
Fir	0.32	118.1	4890	1919	263	125	93	88
Alder	0.50	71.9	5235	3607	415	265	247	128
Hemlock [+]	0.59	44.3	9328	3432	348	195	100 [‡]	- [#]
Maple [+]	0.70	64.8	7910	4068	495 [‡]	325	- [#]	- [#]

[*] One week submersion in water.

[+] Chemically treated for use in fire door frames.

[‡] One test, other specimen failed to tolerate nail.

[#] Both specimens failed to tolerate nail.

TABLE 2-25 FORMULATION FOR FRAMING MATERIAL

Constituent	%
$MgCL_2\ 6H_2O$	26
H_2O	19
MgO	28
MSC Binder	2
Douglas Fir Fibers	6
Silvacon 412	17
Untwisted Sisal	2

Design Selection --The design options on a fire door are limited. The core is limited to one and one half inches for a 90 minute fire rating. The framing materials are also limited to that of conventional design. A cross-section of the door is shown in Figure 2-37. The primary purpose of the groove in the stiles and rails is to element a direct heat or flame path through the wall.

Mechanical Properties --The mechanical requirements for the core are to be light as possible and capable of being handled. The core when completely dried weighs 32 pounds per cubic foot. Existing cores weigh between 20 and 35 pounds per cubic foot which places the waste core in the higher density classification.

The mechanical requirement of the framing material is screw retention. The screw retention of waste framing material is 400 to 450 pounds. This compares favorably with that of conventional wood framing materials whose retention is from 260 pounds to 495 pounds (see Table 2-15).

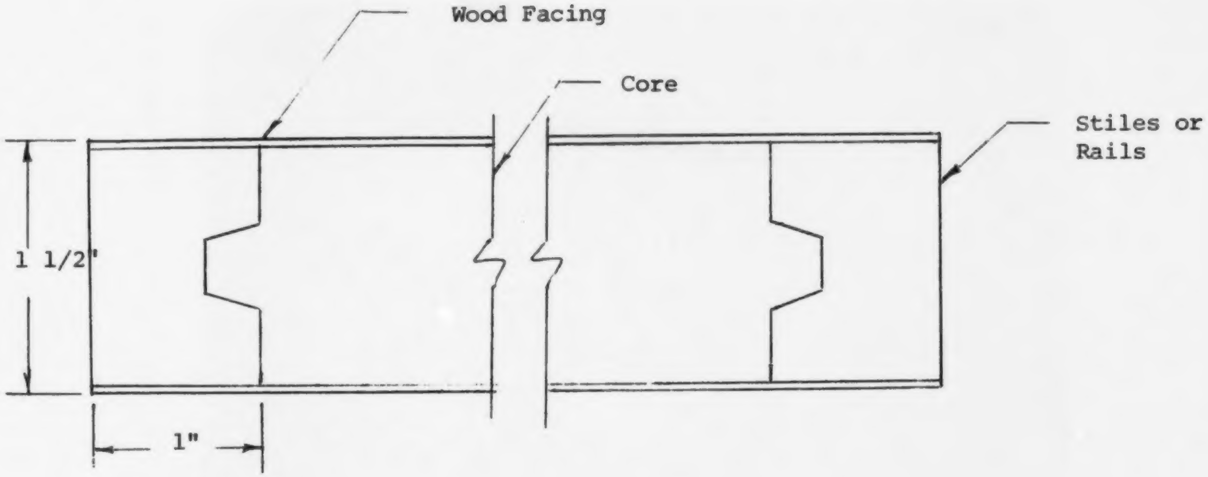
Fire Test --The fire test for the door follows the ASTM E-152 procedure. The time versus temperature requirement is the same as the ASTM E-119 curve shown in Figure 2-18. The difference in procedures is that the door is installed in a wall. The assembly is placed in a furnace for 90 minutes and then removed and sprayed with a 30 psi hose stream for a period of seconds equal to 0.9 times the surface area of the door in square feet.

Preliminary tests were conducted on panels measuring 24 inches by 32 inches by 1 1/2 inches, exposed to a furnace programmed to the ASTM time-temperature curve. Temperature on the back side was measured by thermocouple as was the flame temperature. A small wad of cotton and/or tissue was also kept in contact with the back surface.

After 90 minute exposure the backside temperature was insufficient to ignite the tissue. The specimen was moved to where it was exposed to a stream of water at 30 psi from a 1.5 inch nozzle at a distance of 20 feet. After 8 seconds of such exposure, the sample remained intact. Since the cotton failed to ignite and the back panel was in excellent condition and the water did not wash away all of the core, the test was considered to be very successful (see Figure 2-38).

The results of these tests were sufficient to encourage a full-scale test. Two sets of cores and framing materials were produced under the observation of Warnock Hersey International, Inc. who will conduct the certification tests under the next phase. These elements were shipped to Cal Wood Door for fabrication into a test assembly.

Core Manufacturing Techniques-- The core material is cast into a mold and the mold inserted into a matched platen pressure. The mold is closed to its stops and a pressure of one to two pounds per square inch maintained to equalize pressures generated by the foaming action.


Wood Facing
Core
Stiles or
Rails
1 1/2"
1"

CORE

Figure 2-37. Fire door design.

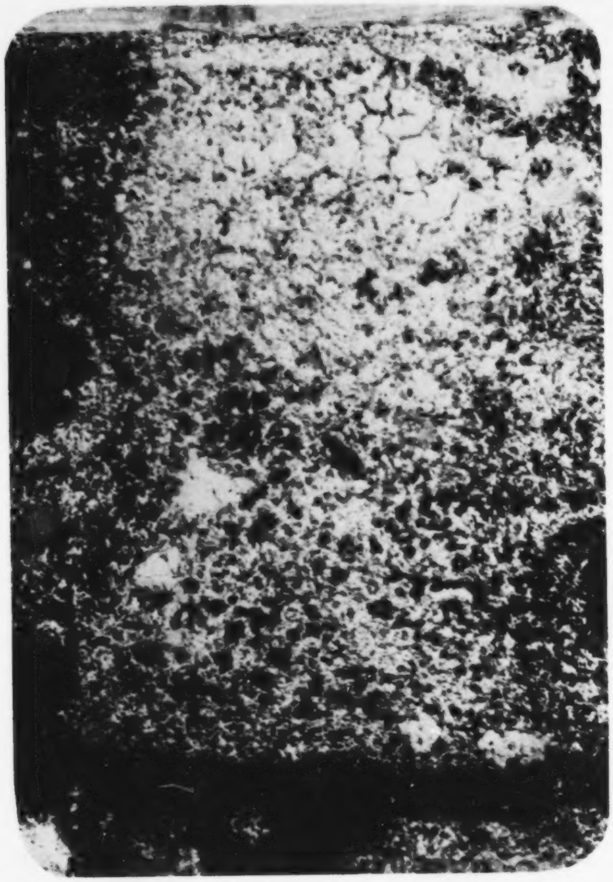


Figure 2-38. Surface after 90-min fire and hose stream.

Framing Material Manufacturing Techniques -- The elements for this study were made in matched molds in a press above. However, the consistency of the compound is such that an extrusion process would be the logical procedure for large quantity production.

Fire Door Product Application and Economics -- The application explored here is the 90 minute fire door. Although there are other cores competing for this market, the only framing material is chemically treated wood which is marginal. The economics of the core are presented in Table 2-26. The material cost of the core is $2.038 for a three foot wide, six foot eight inch high door. Labor costs to produce it would be approximately $1.00 per door. Competitive cores are provided the door manufacturer in a price range of $10.00 to $15.00 per unit. When marketing, distribution and waste expenses are added to the waste door, it would appear to be competitive in that market.

The framing material cost in Table 2-27 of $0.0572 per linear foot is commercially competitive. Furthermore the material is fire resistand and will maintain screw holding power easily for 90 minutes of fire exposure.

The core and framing material can both be utilized in the door industry. It is necessary to generate an interest by a door manufacturer in order to productize this material. This has been accomplished. During Phase IV it is proposed to guide and direct these manufacturers in order to encourage production of doors from waste material.

TABLE 2-26 FIRE DOOR CORE ECONOMICS

Volume	1.896 cubic feet
Dry Weight	60.67 pounds
Wet Weight	79.55 pounds

Item	lbs	Cost/lb	Cost
Rice Hulls	10.9	\$0.062 *	\$0.676
1/2 inch chopped glass fibers	.5	.40	0.200
Casting Plaster	32.7	.0252	0.824
MSC Binder	2.5	.010	0.025
Water	30.2	-	-
$Al_2(SO_4)_3 18H_2O$	2.7	.10	0.270
Detergent	.03	.75	0.023
Retarder	.02	.98	0.020
	79.55		2.038

* Price delivered to factory.

Table 2-27 FRAMING MATERIAL ECONOMICS

1 linear foot = 0.78 lbs

Item	Weight, lbs	Cost/lbs	Total Cost
$MgCL_2 6H_2O$	0.202	\$0.071	\$0.0143
H_2O	0.148	-	-
MgO	0.218	0.135	0.0294
MSC Binder	0.016	0.010	0.0002
Douglas Fir Fibers	0.047	0.060	0.0028
Silvacon 412	0.133	0.075	0.0100
Untwisted Sisal	0.016	0.030	0.0005
Cost per linear foot	-	-	0.0572

SECTION 7

DEMONSTRATION UNIT CONSTRUCTED FROM WASTE MATERIALS

Sheets, panels, and test specimens can define a considerable number of properties and evaluate materials and systems to a point. The true and complete evaluation occurs only when these are incorporated into a complete demonstration unit. Only when floors, roofs and walls are used as such can the real applicability be determined. Therefore, a demonstration unit was designed and built using the previously described waste materials.

It was requested that the unit be disassembleable to permit easy transportation to various exhibition sites. The initial site was the Environmental Protection Agency Environmental Research Center in Cincinnati, Ohio. The disassembly requirement created problems with joints and eliminated weather seal capability which requires that the module be exhibited indoors only. The details of the construction are presented in Appendix E.

The unit constructed is shown in Figure 3-1. The inorganic panels had to be constructed by hand using the techniques previously outlined. Since this was the first production of any large quantity of these materials considerable information was developed on the use of the waste material in housing units. These details are presented below.

ORGANIC WASTE PANELS

Effect of Moisture-- The organic waste panels both wood waste and peanut shells were used as paneling material for both the window and door panels. The construction was accomplished during an extremely humid period. It was determined that the wood waste panels absorbed moisture which caused con iderable swelling. This situation was corrected by sealing the surfaces with a urethane coating. The peanut shell material did not demonstrate the same phenomena.

Applicability-- The organic waste panels were workable with conventional tools and could be nailed without difficulty.

INORGANIC WASTE PANELS

Wall Surface Finish-- In production it is proposed that the desired surface finish be incorporated into the waste wall panels. However, due to the limited hand-built quantities utilized here it was decised to be more efficient for this unit to apply the surface finish as a secondary step. Conventional dry wall spackling compound was used on the interior surfaces and interacted very well with the waste wall.

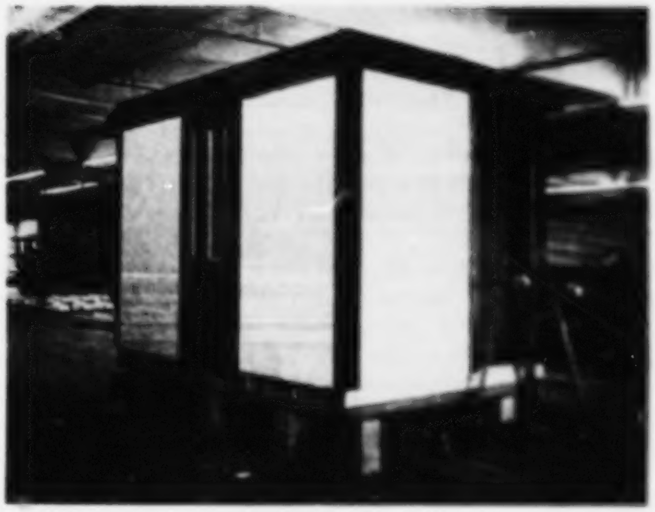


Figure 3-1. Demonstration unit.

Such conventional finished techniques are completely compatible. On the exterior finish a conventional stucco compound was tried first. Although it appeared to work well on small specimens, it did not adhere well on the surface of the module. This material had to be removed.

Laboratory tests showed that magnesium oxy-chloride when mixed with sand made an excellent surface coat. It was originally used as a stucco material before the advent of gypsum stucco. Tests showed that the material interacted with the rice hull foam to affect a good bond. However, on small specimens the effect and mechanics of this interaction were not completely displayed. The magnitude was learned only after the exterior of the unit was coated. An outward curvature towards the magnesium oxy-chloride surface was noted on all walls when the unit was being dismantled for shipment. An upward curvature or crown was noted on the floor panel because the wear surface applied was magnesium oxy-chloride also. However, no curvature was detected in the roof panels which did not receive a magnesium oxy-chloride coat. To verify the effect of magnesium oxy-chloride on the rice hull foam, an eight foot long section of 1/2 inch thick rice hull foam was coated with magnesium oxy-chloride in the same fashion as the unit and observed. The magnesium oxy-chloride penetrated to a depth of 1/4 inch causing an expansion of the rice hull foam which resulted in a curvature towards the coating. Tests indicate no effect on strength. The test specimen indicated that the expansion action after 48 hours. To verify that this action was stabilized, the wall panels were measured over a five day period and no further movement was detected.

Experiments show that if the magnesium oxy-chloride is cast onto the surface at the time the rice hull foam is cast, no curvature is generated. It also appears that if a very thin film of the solution without sand is applied to the cured surface first a seal is created which eliminates excessive amounts of absorbtion of the solution by the rice hull foam when the coating is applied. This eliminates the curvature.

Floor Wear Surface -- The floor panels were uncoated initially. However, after three weeks of technicians working on the interior of the unit, the foam surface showed signs of considerable wear. It was determined to provide a wear surface of magnesium oxy-chloride cement. The results of long term studies discussed in previous sections indicated that the floor panel should be reinforced in both surfaces. Therefore, it was decided to apply a reinforced wear surface of magnesium oxy-chloride cement.

Applicability -- The inorganic waste panels were workable with conventional tools and ordinary construction methods were applicable.

DOORS

Applicability -- The doors required no special consideration and were installed in a similar manner as conventional doors.

APPENDICES

APPENDIX A. INFORMATION SOURCES ON THE ECONOMICS OF PARTICLE BOARD

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APPENDIX B. DATA ON WATER EFFECTS ON RICE HULL REINFORCED INORGANIC MATRIX

TABLE B-1 UNCOATED: RICE HULL REINFORCED INORGANIC MATRIX--WEIGHT DATA

	Original Weight	Weight After 1 Day	Weight After 1 Week	Weight After 1 Month
1	36.7	-	-	-
2	37.4	-	-	-
3	36.8	-	-	-
4	37.4	-	36.2	-
5	36.8	-	36.3	-
6	36.0	-	34.8	-
7	35.7	-	-	34.4
8	35.7	-	-	34.3
9	37.6	-	-	36.1
10	36.6	45.7	-	-
11	36.3	45.2	-	-
12	37.1	46.1	-	-
13	37.3	-	46.8	-
14	34.9	-	44.8	-
15	37.5	-	47.9	-
16	36.5	-	-	48.3
17	36.6	-	-	48.5
18	35.7	-	-	47.1
19	36.9	46.5	-	-
20	37.2	46.2	-	-
21	37.8	46.9	-	-
22	37.3	-	45.6	-
23	36.2	-	45.7	-
24	37.0	-	44.1	-
25	38.0	-	-	39.2
26	38.0	-	-	39.6
27	36.1	-	-	41.8
28	36.8	45.9	-	-
29	36.8	45.3	-	-
30	36.7	46.1	-	-
31	37.9	-	46.8	-
32	37.0	-	46.5	-
33	38.2	-	46.3	-
34	35.2	-	-	47.1
35	37.1	-	-	49.0
36	35.4	-	-	47.6

TABLE B-2 UNCOATED: RICE HULL REINFORCED INORGANIC MATRIX

	Condition	Comp Strength	Avg.	% Ret.
1	Set in	525	-	-
2	open air	580	-	-
3	No water	575	-	-
4	Control	550	-	-
5	Specimens	575	543	-
6		500	-	-
7		545	-	-
8		475	-	-
9		570	-	-
10	1 day Static	300	-	-
11	Water	355	318	58.6%
12	Submersion	300	-	-
13	1 Week Static	345	-	-
14	Water	310	332	61.1%
15	Submersion	340	-	-
16	1 month Static	320	-	-
17	Water	355	325	59.8%
18	Submersion	300	-	-
19	1 day in	310	-	-
20	Water Chg.	335	328	60.4%
21	Daily	340	-	-
22	1 Week in	330	-	-
23	Water Chg.	310	337	62%
24	Daily	370	-	-
25	1 month in	265	-	-
26	Water Chg.	255	280	51.6%
27	Daily	320	-	-
28	1 Day Static	495	-	-
29	Water Sub.	490	492	90.5%
30	Drying Out	490	-	-
31	1 Week Static	595	-	-
	Water Sub		-	-
32	Test After	530	550	101%
33	Dry Out	525	-	-
34	1 Mo. Static	410	-	-
	Water Sub.		-	-
35	Test After	460	445	81.9%
36	Dry Out	465	-	-

TABLE B-3 COATED ZYNOLITE PAINT: RICE HULL REINFORCED INORGANIC MATRIX (COATED)--WEIGHT DATA

	Original Weight	Weight After 1 Day	Weight After 1 Week	Weight 1 Month
1	38.6	-	-	-
2	37.8	-	-	-
3	37.5	-	-	-
4	38.6	-	38.5	-
5	38.2	-	38.2	-
6	38.2	-	38.2	-
7	38.3	-	-	38.3
8	38.6	-	-	38.4
9	38.2	-	-	38.1
10	38.0	47.4	-	-
11	38.2	48.7	-	-
12	38.2	48.8	-	-
13	40.5	-	50.6	-
14	39.1	-	49.8	-
15	38.8	-	49.2	-
16	36.1	-	-	48.7
17	37.6	-	-	50.6
18	38.1	-	-	51.4
19	39.1	50.2	-	-
20	38.0	48.6	-	-
21	38.0	47.2	-	-
22	38.8	-	49.3	-
23	39.2	-	49.1	-
24	38.7	-	48.2	-
25	37.9	-	-	48.9
26	38.4	-	-	50.8
27	38.3	-	-	40.6
28	38.4	49.0	-	-
29	36.6	46.9	-	-
30	38.2	48.7	-	-
31	38.5	-	49.5	-
32	38.5	-	49.5	-
33	38.1	-	48.7	-
34	38.5	-	-	50.8
35	38.8	-	-	51.9
36	39.5	-	-	52.8

TABLE B-4 COATED ZYNOLITE PAINT: RICE HULL REINFORCED INORGANIC MATRIX (COATED)

Condition	Comp Strength	Avg.	% Ret.
1 Set in	610	-	-
2 Open Air	510	-	-
3 No Water	575	-	-
4 Control	500	-	-
5 Specimens	560	581	-
6 -	570	-	-
7 -	585	-	-
8 -	600	-	-
9 -	510	-	-
10 1 Day Static	320	-	-
11 Water	335	325	55.9%
12 Submersion	320	-	-
13 1 Week	335	-	-
Static	-	-	-
14 Water	325	307	52.8%
15 Submersion	260	-	-
16 1 Month	265	-	-
Static	-	-	-
17 Water	350	307	52.8%
18 Submersion	305	-	-
19 1 Day in	315	-	-
20 Water Chg.	340	335	57.6%
21 Daily	350	-	-
22 1 Week in	350	-	-
23 Water Chg	355	352	60.5%
24 Daily	350	-	-
25 1 Month in	305	-	-
26 Water Chg.	325	335	57.6%
27 Daily	375	-	-
28 -	-	-	-
29 Did not Dry	-	-	-
30 Specimens	-	-	-
31 1 Week Static	600	-	-
Water Sub.	-	-	-
32 Test After	600	612	10.5%
33 Dry Out	635	-	-
34 1 Mo Static	-	-	-
Water Sub.	490	-	-
35 Test After	525	501	86.3%
36 Dry Out	490	-	-

TABLE B-5 COATED LYTRON 621: RICE HULL REINFORCED INORGANIC MATRIX (COATED)--WEIGHT DATA

	Original Weight	Weight After 1 Day	Weight After 1 Week	Weight 1 Month
1	35.7	-	-	-
2	35.5	-	-	-
3	36.4	-	-	-
4	35.5	-	35.7	-
5	35.8	-	35.8	-
6	35.3	-	35.6	-
7	36.1	-	-	36.2
8	34.8	-	-	35.0
9	35.4	-	-	35.5
10	35.6	46.9	-	-
11	34.8	46.5	-	-
12	35.6	46.5	-	-
13	34.9	-	46.3	-
14	34.3	-	45.5	-
15	35.7	-	46.6	-
16	35.1	-	-	49.2
17	35.7	-	-	49.4
18	34.8	-	-	48.3
19	35.9	47.0	-	-
20	35.4	46.2	-	-
21	36.0	46.8	-	-
22	35.8	-	46.6	-
23	35.7	-	46.5	-
24	34.5	-	44.7	-
25	36.1	-	-	45.6
26	35.2	-	-	44.9
27	35.3	-	-	45.2
28	35.2	46.5	-	-
29	35.3	45.8	-	-
30	35.5	46.5	-	-
31	34.4	-	46.4	-
32	35.3	-	46.3	-
33	35.6	-	47.1	-
34	35.4	-	-	49.3
35	34.4	-	-	48.4
36	35.2	-	-	48.3

TABLE B-6 COATED LYTRON 621: RICE HULL REINFORCED INORGANIC MATRIX (COATED)

	Condition	Comp Strength	Avg.	% Ret.
1	Set In	555	-	-
2	Open Air	510	-	-
3	No Water	500	-	-
4	-	400	-	-
5	Control	465	484	-
6	Specimens	485	-	-
7	-	480	-	-
8	-	380	-	-
9	-	475	-	-
10	1 Day Static	305	-	-
11	Water	275	287	59.2%
12	Submersion	280	-	-
13	1 Week Static	295	-	-
	Water			
14	Submersion	285	317	65.4%
15	-	370	-	-
16	1 Month	335	-	-
17	Static Water	330	327	61.5%
18	Submersion	315	-	-
19	1 Day in	310	-	-
20	Water Chg.	335	320	66.1%
21	Daily	315	-	-
22	1 Week in	270	-	-
23	Water Chg.	245	267	55.1%
24	Daily	285	-	-
25	1 Month in	300	-	-
26	Water Chg.	205	287	59.2%
27	Daily	265	-	-
28	Did Not	-	-	-
29	Dry	-	-	-
30	Specimens	-	-	-
31	1 Week Static	510	-	-
	Water Sub.			
32	Test After	550	535	110%
33	Dry Out	545	-	-
34	1 Mo. Static	470	-	-
35	Water Sub.			
	Test After	490	468	96.7%
36	Dry Out	445	-	-

TABLE B-7 COATED W-102: RICE HULL REINFORCED INORGANIC MATRIX (COATED)--WEIGHT DATA

	Original Weight	Weight After 1 Day	Weight After 1 Week	Weight After 1 Month
1	38.1	-	-	-
2	38.1	-	-	-
3	37.9	-	-	-
4	38.2	-	38.2	-
5	38.1	-	38.1	-
6	38.7	-	38.6	-
7	37.0	-	-	37.1
8	37.4	-	-	37.4
9	37.2	-	-	37.2
10	38.5	49.5	-	-
11	37.5	48.4	-	-
12	37.4	48.2	-	-
13	38.1	-	49.6	-
14	37.4	-	48.5	-
15	39.3	-	50.8	-
16	38.3	-	-	52.6
17	38.8	-	-	53.1
18	38.5	-	-	52.6
19	38.6	49.5	-	-
20	38.0	48.6	-	-
21	38.0	48.8	-	-
22	38,4	-	49.9	-
23	37.8	-	48.7	-
24	38.2	-	49.6	-
25	36.8	-	-	48.3
26	38.1	-	-	49.9
27	37.7	-	-	50.0
28	37.8	48.6	-	-
29	38.0	48.6	-	-
30	37.7	48.2	-	-
31	37.5	-	48.9	-
32	38.2	-	49.9	-
33	37.9	-	49.5	-
34	38.2	-	-	52.2
35	37.5	-	-	52.0
36	38.2	-	-	52.7

TABLE B-8 COATED W-102: RICE HULL REINFORCED INORGANIC MATRIX (COATED)

	Condition	Comp Strength	Avg.	% Ret.
1	Set in	555	-	-
2	Open Air	525	-	-
3	No Water	540	-	-
4	-	515	-	-
5	Control	545	527	-
6	Specimens	555	-	-
7	-	485	-	-
8	-	535	-	-
9	-	490	-	-
10	1 Day Static	300	-	-
11	Water	305	290	55%
12	Submersion	265	-	-
13	1 Week Static	320	-	-
14	Water	285	367	58.2%
15	Submersion	315	-	-
16	1 Mo. Static	315	-	-
17	Water	310	312	59.1%
18	Submersion	310	-	-
19	1 Day in	310	-	-
20	Water Changed	260	277	52.5%
21	Daily	260	-	-
22	1 Week in Water	310	-	-
23	Changed	320	297	56.3%
24	Daily	260	-	-
25	1 Month in water	275	-	-
26	Changed	305	293	55.7%
27	Daily	300	-	-
28	1 Day Static Water Sub.	325	-	-
29	Test After	310	328	62.3%
30	Dry Out	350	-	-
31	1 Week Static Water Sub.	335	-	-
32	Test After	370	338	64.2%
33	Dry Out	310	-	-
34	1 Mo. Static Water Sub.	460	-	-
35	Test After	435	463	87.9%
36	Dry Out	495	463	87.9%

TABLE B-9 KILN-DRIED DOUGLAS FIR LUMBER--WEIGHT DATA

	Original Weight	Weight After 1 Day	Weight After 1 Week	Weight 1 Month
1	15.3	-	-	-
2	14.8	-	-	-
3	15.3	-	-	-
4	-	-	-	-
5	-	-	-	-
6	-	-	-	-
7	-	-	-	-
8	-	-	-	-
9	-	-	-	-
10	-	-	-	-
11	-	-	-	-
12	-	-	-	-
13	15.5	-	24.6	-
14	15.5	-	24.2	-
15	17.4	-	26.0	-
16	15.7	-	-	29.6
17	15.0	-	-	28.9
18	15.4	-	-	29.8

TABLE B-10 KILN-DRIED DOUGLAS FIR LUMBER

	Condition	Comp Strength	Avg.	% Ret.
1	Test Dry	5150	-	-
2	Control	5400	5383	-
3	Specimen	5600	-	-
4	-	-	-	-
5	-	-	-	-
6	-	-	-	-
7	-	-	-	-
8	-	-	-	-
9	-	-	-	-
10	-	-	-	-
11	-	-	-	-
12	-	-	-	-
13	1 Week Static	3050	-	-
14	Water	3000	3117	57.9%
15	Submersion	3300	-	-
16	1 Mo. Static	2950	-	-
17	Water	2950	2967	55.1%
18	Submersion	3000	-	-

PHASE IV SUMMARY REPORT

SECTION 1
INTRODUCTION

Material Systems Corporation and the Solid and Hazardous Waste Research Division of the Municipal Environmental Research Laboratory at Cincinnati, Ohio, have conducted a joint development study of the application of waste materials to residential and commercial construction. This is a summary report of the Phase IV activity.

Results of previous work have been reported in summary reports for each phase. Only a brief resume of these results is presented here for the convenience of the reader to serve as an introduction to the detailed discussion of Phase IV.

In Phase I, a comprehensive literature search was conducted on potential matrix, reinforcement and filler candidates. The more promising candidates were evaluated in laboratory studies. From these studies, two types of matrices (furfural derivatives and inorganics) were selected for evaluation with the two matrices.

The Phase II activity demonstrated the potential technical and economic feasibility of utilizing waste materials for building construction. As the Phase II study progressed, it became apparent that there existed many product possibilities from waste materials. Therefore it was jointly decided to concentrate Phase II activity on product development and to postpone specific qualifications until Phase III.

The product development effort included testing and evaluation to a sufficient level to assure probable qualification for specific products. The products selected for qualification studies in Phase III were in two main categories: those materials from organic matrices and those from inorganic matrices.

The Phase III study selected wood waste and peanut shells for possible qualification as organic particle board. Panels as large as 4 by 4 feet were fabricated and tested. However, not all the processing problems were resolved; this would require further studies. The wood waste particle board probably has some economic advantage over commercial particle boards. The economic advantage of the peanut shell board is marginal. With the resolution of some of the processing problems, the boards could probably be qualified. Their principal limitation is high density: boards from this process have a minimum weight of 55 pounds per cubic foot.

The Phase III study also selected a composite made of rice hulls and an inorganic matrix for use as walls, floors, roof-ceiling, and floor-ceiling systems. A satisfactory load carrying 2-hour fire-rated wall was developed. Acceptable floor, floor-ceiling, and roof-ceiling systems were also developed. These building components appear to offer a cost advantage over conventional structures and to lend themselves to mass production techniques. Further studies were recommended on the problem of long-term loading and were carried out in Phase IV, as described in this report.

The rice-hull foam mentioned above was modified to be used as a core for fire doors. A screwable framing material from wood-waste-reinforced inorganic matrix was also developed. The resulting core and framing materials both have economic advantages and offer a more reliable 90-minute fire door than do those commercially available.

The final activity in Phase III was the construction of an 8-foot wide, 12-foot long demonstration unit incorporating all of the above products.

In Phase IV, wall panels constructed with the rice hull/inorganic matrix composite were subjected to further structural tests to generate additional data in support of possible future qualification for building code approval.

Structural tests consisted of racking shear, tranverse load, and long-term weathering exposure.

Both a 1-hour fire test and a hose stream test were performed on a wall assembly to complete the structural fire rating qualification initiated during Phase III.

The material processing development work on fire door components was continued. Detailed results of this work are presented in the following sections of this report.

SECTION 2
STRUCTURAL TESTS OF WALL PANELS

A structural test program on wall panels made of rice hull/inorganic matrix composice was started during Phase III in the generation of data required to qualify the wall panels for building code approval.

The requirements set by the International Conference of Building Officials (ICBO) were used as the basis for the test program. ICBO is the regulating body of the Uniform Building Code, one of the three major codes used in the United States. The ICBO requirements were selected because of MSC's prior experience with the ICBO qualification procedure (gained during approval of its Duftec* wall panel system).

Four types of test are required for structural qualification of wall panels under the ICBO requirements: axial compression, tranverse loading, racking shear and impact test.

Considerable testing was conducted in Phase III,as reported in the Phase III Summary Report; however, additional testing was considered necessary to support qualification of the wall panels in order to obtain approval of the maximum potential allowable design loads.

The additional tests conducted during Phase IV were transverse loading, racking shear and long-term weathering exposure.

TRANSVERSE LOAD TESTS

Three 48- by 96-in. wall panels were tested in transverse loading in accordance with ASTM-E-72 test methods. The tests were conducted by MSC in its own test facilities under the supervision of San Diego Testing Engineers Inc.

Results of the tests are presented in Figure 1. As indicated by these load vs deflection curves, the wall panels are sufficiently stiff that ultimate load, rather than the deflection criterion, determines the allowable design loads. (The deflection criterion of L/180 would permit a maximum deflection of 0.53 in., but all three panels failed at less than half that value.)

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*Duftec is a proprietary reinforced plastic material developed by MSC for use in structural building components.

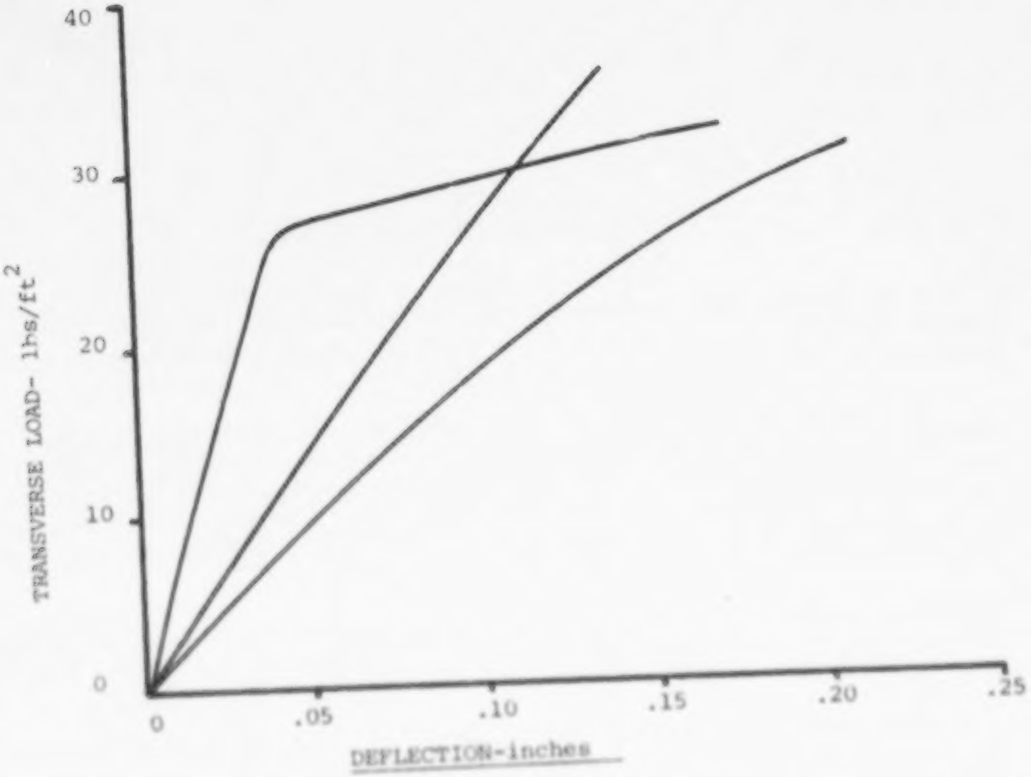

Figure 1. Transverse Load vs Deflection Curves for Rice Hull/Inorganic Matrix Wall Panels

The average failure load of 32.67 lb/ft^2 will result in an allowable transverse load of 10.89 lb/ft^2 based on a safety factor of 3. This is not sufficient to satisfy the minimum wind load requirements of 15 lb/ft^2 specified by the Uniform Building Code.

In order to improve the transverse load (bending) resistance of the walls, additional reinforcement would be required near the surface to increase tensile strength of the outer layers in bending. Reinforcing fibers or fabrics could be incorporated in a surface coating. The need for a surface coating, which would provide moisture protection, will be discussed in the section on the long-term weather exposure tests.

RACKING SHEAR TESTS

Racking shear tests conducted in Phase III were made on wall panels with the top and bottom wood plates bonded with adhesive. It was decided to repeat these tests with the wood plates nailed rather than bonded.

Three 48- by 96-in. wall panels were tested in accordance with ASTM-E-72 test methods. The tests were conducted by MSC in its own test facilities under the supervision of San Diego Testing Engineers Inc.

Results of the test are shown in Figure 2. From the corrected load-vs-deflection curves, the allowable racking shear load is determined based on the deflection or ultimate load criterion, as specified by ICBO.

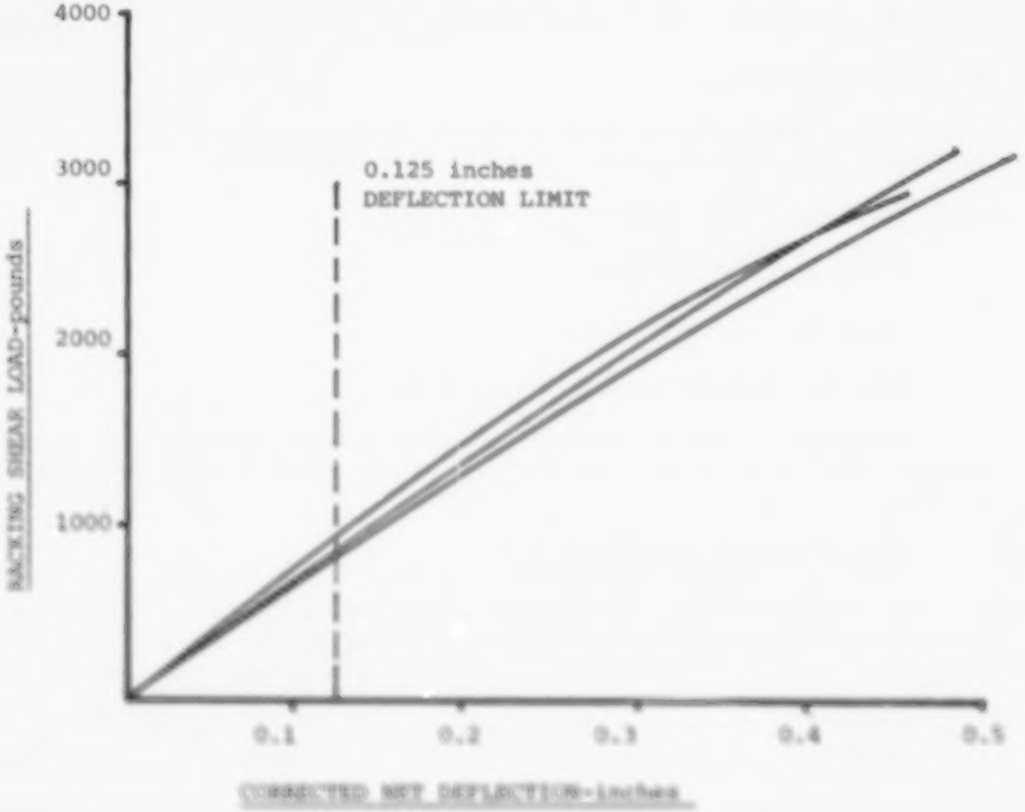

Figure 2 Racking Shear Load vs Deflection Curves for Rice Hull/Inorganic Matrix Wall Panels Nailed to Top and Bottom Plates

Ultimate Load Criterion

The ultimate load obtained for each panel is divided by the width of the panel and by a safety factor 3. The average of the three resulting loads is the allowable load.

Panel #1: $\frac{3250 \text{ lb}}{4 \text{ ft} \times 3} = 270.83 \text{ lb/ft}$

Panel #2: $\frac{3250 \text{ lb}}{4 \text{ ft} \times 3} = 270.83 \text{ lb/ft}$

Panel #3: $\frac{3000 \text{ lb}}{4 \text{ ft} \times 3} = 250.00 \text{ lb/ft}$

Average: Allowable Load = 263.89 lb/ft

Deflection Criterion

The allowable design load based on the deflection criterion is the average of the loads obtained at 0.125 inch deflection.

Panel #1: 800 lb/4 ft = 200 lb/ft

Panel #2: 800 lb/4 ft = 200 lb/ft

Panel #3: 920 lb/4 ft = 230 lb/ft

Average: Allowable load = 210 lb/ft

Since the allowable load based on the deflection criterion results in the lower value, it will govern design and would be the value approved by ICBO.

LONGTERM WEATHERING EXPOSURE TESTS

The results of structural tests conducted in Phase III indicated that wallpanels and other structural components developed in this program have sufficient initial strength to satisfy design load requirements for one- and two-story residential construction. The principal remaining question was the effect of long-term weathering on the strength of these components. Test were devised, exposing typical wall panels to the following conditions.

(a) continuous axial compression load of 250 lb/ft, normal outdoor ambient exposure (Escondido, Calif.)

(b) continuous axial compression load of 250 lb/ft, continuous rain soak exposure (simulated by continuous water film running over one exterior surface)

(c) no load; repeated 24-hour cyclic exposure of one face to:

6 hours at -20°F

6 hours warm up to 120°F

6 hours at +120° F, with 1 hour water spray
at beginning and at end

6 hours cool down to -20°F

Tests (a) and (b) were performed in specially constructed loading fixtures at MSC's Escondido facility (illustrated in Figure 3), Test (c) was performed in MSC's cyclic environmental chamber (illustrated in Figure 4).

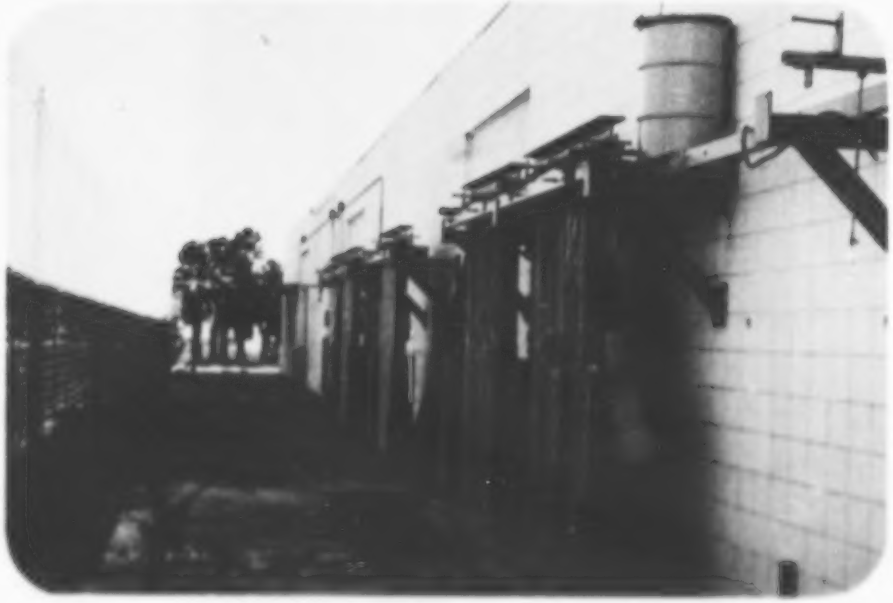

Figure 3 Long-Term Exposure Test Fixtures

Visual observations of wall panels in tests (a) and (b) indicated severe surface cracking of all specimens. In the case of the water-soaked panels, the surface of the wall degraded to a point at which it could be easily punctured by the push of a finger.

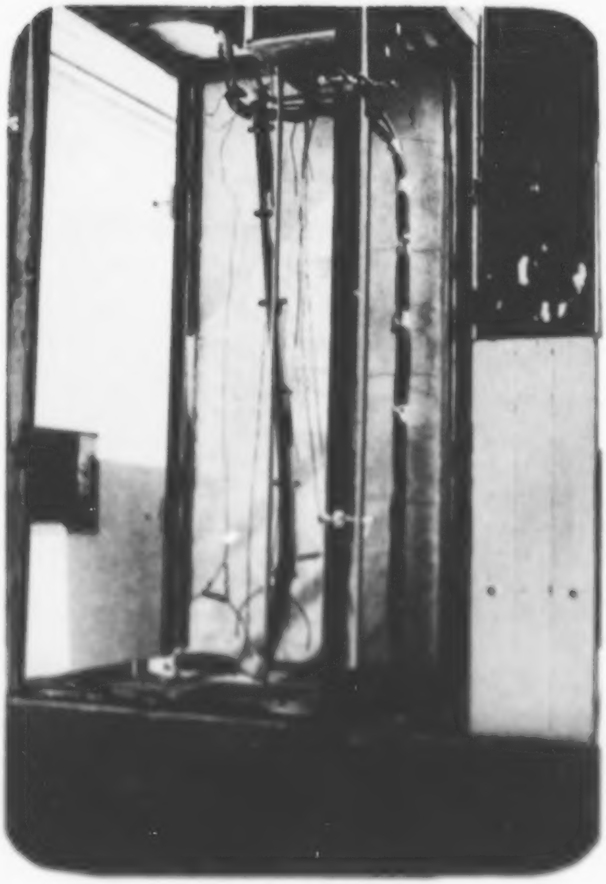

Figure 4 Cyclic Environmental Chamber

The axial and lateral deflection of the continuously loaded specimens were recorded. (Deflection history curves for two rain-soaked panels are presented in Figure 5). Deflection was substantial in the first 30 days but appeared to level off after that. This would indicate that most of the water-caused degradation occurs during the first month. Of course, the deflection could be caused by warping due to the asymmetrical water exposure; if so, once the wet face was completely saturated, the warping would stabilize.

There was no measurable deflection of the panels exposed to the outdoor environment in Escondido.

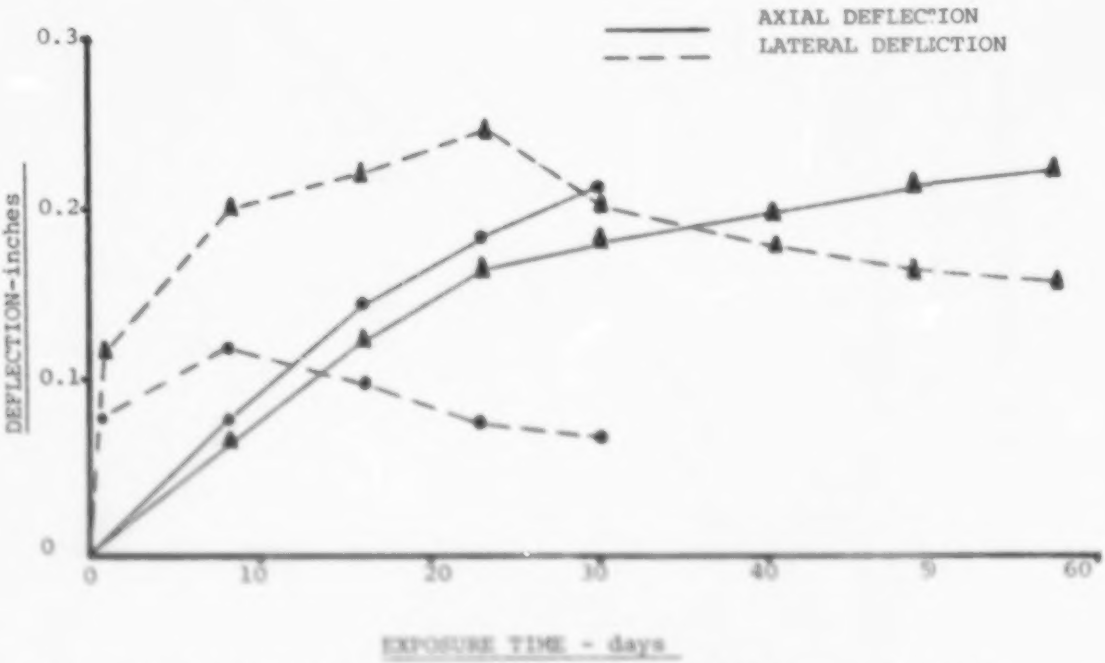

Figure 5 Axial and Lateral Deflection of Rice Hull/Inorganic Mtrix Wall Panels During Long-Term Rain Soak Exposure, Under Constant Axial Load of 250 lb/ft

One rain-soaked wall panel was removed for testing after 30 dys and one after 60 days of exposure. The walls were tested in axial compression following a 30-day dry-out period. Test results (presented in Figure 4 show a drastic reduction in both stiffness and ultimate strength after 30 days of exposure. The wall exposed for 2 months shows some further reduction in stiffness, but the failure load was actually slightly higher than hat of the 30-day specimen.

The difference between the 30- and 60-day results is not considered significant; it is apparent that most of the degradation takes plce in the first 30 days of exposure to rain.

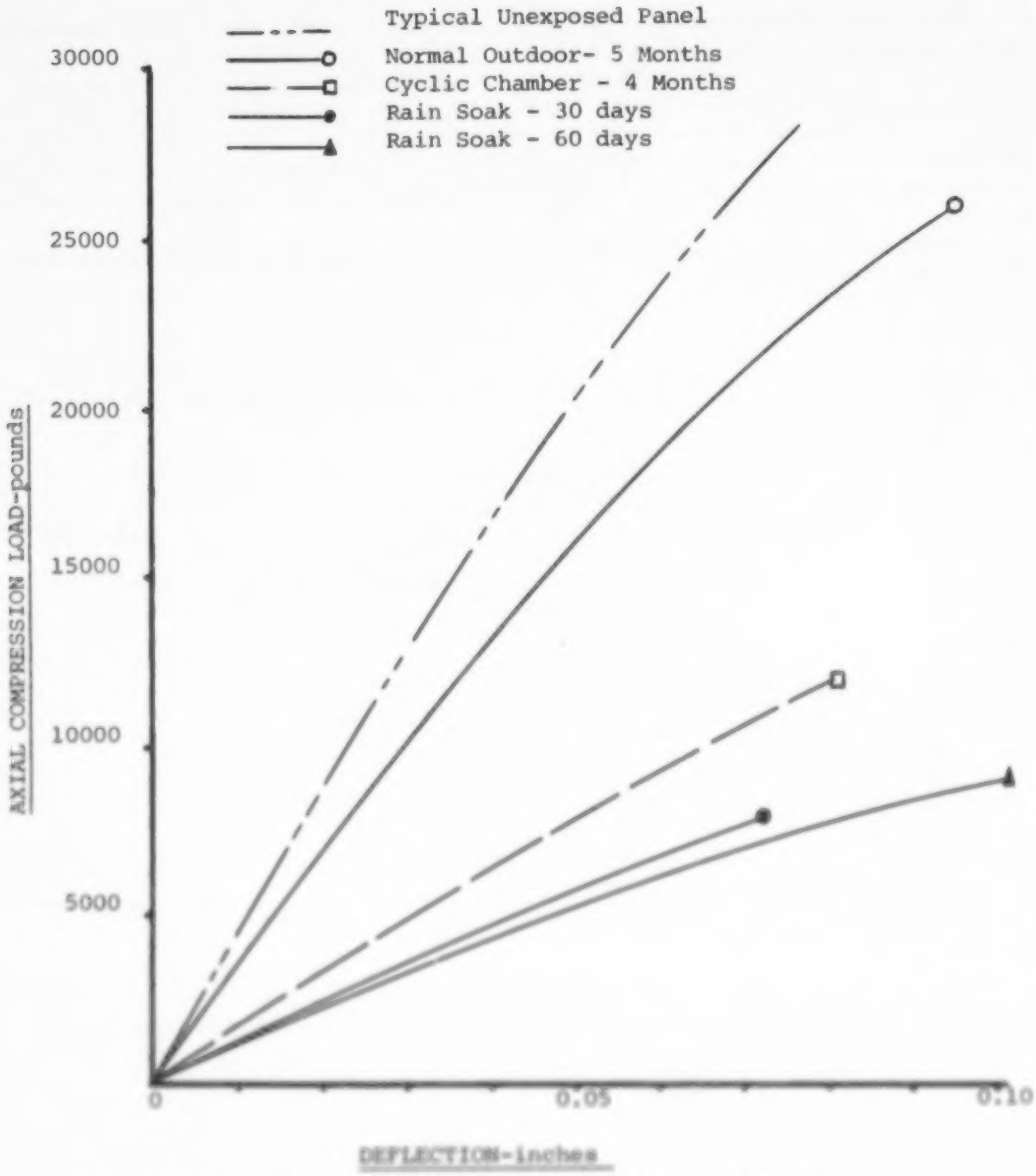

Figure 6 Axial Compression Load vs Deflection Curves for 4- by 8-ft Rice Hull/Inorganic Matrix Wall Panels After Various Long-Term Exposures

The two wall panels in the cyclic environment chamber were exposed for about 4 months to the repeated test cycle (C); the chamber then was shut down and the panels left in the chamber for 30 days to dry out. Visual inspection of the exposed face of the panels indicated that the surface cracks were similar to those of the rain-soaked panels.

One of these panels was tested in axial compression (test results are shown in Figure 6). Interestingly, this wall retained more of its original stiffness and strength than the rain-soaked walls, indicating that water has the most severe damaging effect on the rice hull/inorganic matrix composite.

One of the wall panels under continuous load in the outdoor environment for 5 months was also tested in axial compression. This wall failed at 26,400 lb, which is only a 12% reduction from the typical initial strength of unexposed panels. This panel was severely cracked on the surface in a fashion similar to the rain-soaked walls, but the material remained hard. The deflection curve shown in Figure 6 indicated that this panel retained most of its original stiffness.

In conclusion, the results of the long-term exposure tests clearly indicate that the rice hull-inorganic matrix material of the walls tested is very sensitive to water damage. If these materials are to be used as building components, they must be protected from prolonged exposure to water. It is therefore recommended that future work should explore the development of surface coatings. The coatings should perform two basic functions:

a) provide moisture protection and thereby prevent the degradation of the rice hull/inorganic matrix composite;

b) reinforce the exterior surface of the panels against stress cracking and thereby increase the tensile strength of the facings, which will in turn improve the lateral load resistance (flexural strength) of the wall panels.

SECTION 3
FIRE TEST OF WALL

Several full-scale, ASTM-E-19 fire tests were conducted on wall assemblies in Phase III of this program to obtain a 2-hour structural fire rating.

The results fell short of the 2-hour goal. The tests were repeated with a 1-hour objective.

The first of the two-part test was successfully performed during Phase III. The second part, the so-called hose stream test, was completed in Phase IV: it was performed by the University of California Fire Test Laboratory at Richmond, California. During this test, the wall assembly, 8 feet high and 12 feet wide, is exposed to fire for half an hour in accordance with the procedures specified in ASTM-E-13 test methods. At the end of the 30 minutes, the temperature in the furnace reaches over 1500°F. One surface of the wall panel is directly exposed to this temperature. At the same time the wall is under a constant axial compression load of 100 pound per linear foot.

The wall assembly is then removed from the furnace and subjected immediately to high pressure water spray, simulating fire hose exposure in real fire, for 1 minute. The water must not penetrate through the panel for the wall to be acceptable for 1 hour fire rating. In addition, at the end of the hose stream test, the axial compression load is increased to twice the required design load. The wall must not fail under the increased load.

The rice hull/inorganic matrix wall assembly successfully passed the entire test and thereby qualified for a 1-hour structural fire rating with an allowable design load of 1000 lb/ft.

SECTION 4
FIRE DOOR DEVELOPMENT

The work performed in the previous phases of this study resulted in the development of new core and framing materials for use in fire doors.

After extensive material screening and processing studies conducted on laboratory-scale samples at the end of Phase IV, components have been fabricated successfully for full-scale fire doors.

Preliminary fire tests indicate that these new materials perform better than commercially available door components. It also appears that in commercial-scale production, the new materials would be competitive in cost with currently used materials.

Having demonstrated the technical feasibility and the cost-effectiveness of using waste materials in a commercial product (in this case a 90-minute fire-rated door), the emphasis in Phase IV was concentrated on getting a manufacturer interested in using the new materials in actual production.

Calwood Door, a cabinet and door manufacturer, has shown considerable interest. Calwood assisted during the earlier phases of the development effort by providing performance requirements and realistic full-scale fabrication parameters to guide MSC in laboratory studies.

After the successful preliminary fire test, Calwood agreed to evaluate full-scale production processing. Sample components were fabricated by MSC and incorporated into full-scale doors by Calwood. The manufacturer identified several production problems with the use of the new materials, and MSC developed solutions.

For example, Calwood experienced difficulty in bonding the framing components to the wood facing sheets. Laboratory tests were conducted by MSC to find suitable adhesives to eliminate this production problem.

Results of tests performed on the two most promising candidate adhesives are presented in Table 1. The test consisted of bonding blocks of the framing material to wood block using the candidate adhesives. The bonded blocks were then tested in tension at room temperature and at 300°F. The use of "veil mat" as a reinforcement of the bond interface was also evaluated in these tests.

From the results of these tests, it was concluded that both of the adhesives would perform satisfactorily. The results also indicated that the use of the veil mat did not increase the strength of the bond. In fact, at elevated temperature, the specimens with veil mat showed lower strength than the ones without it.

Based on these results, the manufacturer repeated his earlier production experiments with the new adhesives and found that they both performed well.

Table 1 FIRE DOOR ADHESIVE TESTS

Borden 07-100 (Casein) Adhesive

Without Veil Mat Failure Load, lb @ R.T.	Type of Failure	With Veil Mat Failure Load, lb @ R.T.	Type of Failure
615	Block Broke	630	Block Broke
495	" "	660	" "
780	" "	635	" "
620	" "	605	" "
525	" "	610	" "
Avg 607		Avg 628	
Tested @ 300°F		Tested @ 300°F	
420	Block Broke	380	Block Broke
515	" "		" "
440	" "	420	" "
520	" "	455	" "
490	" "	430	" "
Avg 477	" "	Avg 436	" "
22% loss in material strength		31% loss in material strength	

Borden RS-125 MD (Resorcinol) Adhesive

Without Veil Mat Failure Load, lb @ R.T.	Type of Failure	With Veil Mat Failure Load, lb @ R.T.	Type of Failure
620	Block Broke	565	Block Broke
630	95% Adhesive Failure	685	" "
750	Block Broke	645	" "
575	" "	705	" "
655	" "	575	" "
Avg 644		Avg 635	
Tested @ 300°F		Tested @ 300°F	
535	Block Broke	415	Block Broke
430	" "	450	" "
520	" "	420	" "
515	" "	460	" "
470	" "	455	" "
Avg 494		Avg 440	
23% loss in material strength		31% loss in material strength	

As a conclusion to this study a door fabricated with waste material components developed in this program was fully qualified as a 90-minute rated fire door.

Based on the results of this study, Calwood Door is planning to introduce in next year's product line a new high-performance fire door using components made from waste materials.